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DEPARTMENT OF MARINE BIOLOGY

OF

THE CARNEGIE INSTITUTION OF WASHINGTON

ALFRED G. MAYOR, DIRECTOR

PAPERS
FROM THE DEPARTMENT OF MARINE BIOLOGY

OF THE

CARNEGIE INSTITUTION OF WASHINGTON

VOLUME XVIII

PUBLISHED BY THE CARNEGIE INSTITUTION OF WASHINGTON

WASHINGTON, NOVEMBER, 1922

CARNEGIE INSTITUTION OF WASHINGTON

PUBLICATION No. 312

Copies of this book
first issued
DEC 1 2 1922

TECHNICAL PRESS
WASHINGTON, D. C.

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I.

STUDIES ON THE HYBRIDIZATION OF ECHINOIDS, CIDARIS TRIBULOIDES.

By DAVID H. TENNENT,

Bryn Mawr College.

Three plates, twenty-eight figures.

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STUDIES ON THE HYBRIDIZATION OF ECHINOIDS.

By David H. Tennent.

PART I. EMBRYOLOGY AND HYBRIDIZATION OF CIDARIS.

In 1912, at Montego Bay, Jamaica, I obtained material and began the study of straight-fertilized eggs of *Cidaris tribuloides* Lamarck, of *Cidaris* eggs fertilized with the sperms of *Lytechinus* (*Toxopneustes*) *variegatus*, of *Cidaris* eggs fertilized with the sperms of *Tripneustes* (*Hipponoë*) *esculenta*, and of *Cidaris* eggs caused to develop parthenogenetically. A brief account of some of the facts determined appeared in Publication No. 182 of the Carnegie Institution of Washington. The present paper includes my completed observations.

Nature and Systematic Position of the Material.

The nature and systematic position of the forms used demand more than passing notice. *Cidaris* represents the lower extreme of a series extending from little specialized to highly specialized Echinoids; *Lytechinus* and *Tripneustes* represent the upper extreme. Jackson (1912) has shown that the Cidaroida are primitive, extending from the Lower Carboniferous to Recent times. He says:

"The most primitive type of Echini, I believe emphatically, is *Bothriocidaris* [p. 208]. . . . The order Cidaroida is placed as derived directly from the Bothriocidaroida without known intermediate forms. The Cidaridæ, as regards the structure of the young and adult, are the least removed from *Bothriocidaris* of any known echinoid, living or fossil" [p. 211].

Lytechinus and *Tripneustes* are members of the order Centrechinoida (Triassic to Recent), of the suborder Camarodonta, and of the family Echinidæ (Cretaceous to Recent). Again quoting from Jackson (p. 210):

"The sub-order Camarodonta may be considered the most specialized of modern regular Echini on the basis of the lantern, and also in various genera by the sculptured test, the degree of specialization of the ambulacrum, peristome, perignathic girdle, or the elliptical form through a sidewise axis."

In discussing the lantern, Jackson says (p. 187) that "*Tripneustes* represents the most complex structure known in the Centrechinoida."

H. L. Clark (1912, p. 365), in his consideration of the Echinometridæ, says:

"There can be little question that this family includes the most highly specialized of the regular recent Echini, for the elongation of one axis, when combined with highly developed ambulacra, indicates an unusual complexity of structure. And yet in the

characters of the abactinal system and the globuliferous pedicellariæ, the most specialised Echinidæ, such as *Tripneustes*, are apparently more advanced than any of the Echinometridæ, and it is therefore merely a matter of opinion whether *Tripneustes* or *Heterocentrotus* is considered the 'highest' of the regular Echini."

These ideas, based upon a morphological and palæontological consideration of Echinoids, have an added significance and interest when we find that *Cidaris* is also primitive in its development. *Cidaris* shows some processes of development that have not been described, so far as I know, for any other Echinoid, and in one phase of its early development resembles the Crinoids and Holothurians more closely than it does the Echinoids. The material has also given an opportunity for the study of the results following the insemination of the egg of a species having a primitive type of development with sperms of species having a modern type of development.

Lytechinus and *Tripneustes* are about as widely removed from *Cidaris* as it is possible for them to be and remain in the same class. *Lytechinus* and *Tripneustes* are of the order Centrechinoida; *Cidaris* is of the order Cidaroida. Crosses between these forms are therefore interordinal, and in themselves are of a good deal of interest.

Conklin (1915, p. 176) has stated the generally accepted belief regarding the respective potency of egg and spermatozoon in heredity:

"At the time of fertilization the hereditary potencies of the two germ-cells are not equal, all the early stages of development, including the polarity, symmetry, type of cleavage, and the pattern, or relative positions and proportions of future organs, being foreshadowed in the cytoplasm of the egg-cell, while only the differentiations of later development are influenced by the sperm. In short, the egg cytoplasm fixes the general type of development and the sperm and egg nuclei supply only the details."

There has been a considerable amount of interest concerning the time at which the influence of the sperm first becomes evident. The material at hand enables us to push back our determination of the time of appearance of paternal influence succeeding fertilization to a point beyond that which has previously been reached and established, but it is also convincing in its proof of the lack of plasticity in the egg, of the inability of the egg to follow a system of development which is not its own. The egg cytoplasm is the material which is to be differentiated, but it does not seem to be able to harmonize its inherent system of development with a foreign system.

Most of the successful crosses between Echinoderms have been within one suborder of the order Centrechinoida. The cleavage pattern and the early development of the forms considered have afforded no landmarks for the guidance of the observer. In this *Cidaris* and *Cidaris-Lytechinus-Tripneustes* material there is a definite, visible specificity of development, and it is possible to see the exact period at which the disharmony between two systems of development begins.

This study has been based on an examination of both living and fixed material. The development of the straight-fertilized eggs was followed through 6 days. Plutei were kept alive for 2 weeks, but did not advance strikingly beyond the stage of development shown by the 6-day larvæ. The cultures were kept in finger-bowls and the larvæ were given a complete change of water daily, after the third day, by transferring the contents of the bowls to centrifuge tubes and centrifugalizing gently, thus throwing the larvæ to the ends of the tubes, then withdrawing the water from above the larvæ and replacing with fresh sea-water. The plutei treated in this manner kept in better condition than those not centrifugalized, but their rate of growth was slow. The general form of the larvæ changed very slightly, but there was some increase in the size of the skeleton.

I was at first of the opinion that the sole cause of the slow rate of growth was an inadequate supply of food, but the observations of Prouho and Mortensen on developing *Cidaris* larvæ have caused me to change my opinion to the extent of believing that, even though the quantity of food available was somewhat below normal, this was not the only cause of what seems a slow rate of growth when compared with that of other Echinoid larvæ. Development in *Cidaris* is apparently slow; these larvæ may have been growing at nearly the normal rate.

Because of limited time, no attempt was made to rear the larvæ to metamorphosis by the use of cultures of diatoms. Material was fixed in sublimate-acetic (98 c. c. saturated aqueous solution of corrosive sublimate plus 2 c. c. glacial acetic acid), for 15 minutes. For some purposes, portions of this material have been stained *in toto* and mounted entire; for other purposes portions of the material were embedded in paraffine in the usual way, cut into sections of 5 or 7 microns, and stained by Heidenhain's iron hæmatoxylin method. Larvæ kept for the study of skeletal rods were killed in fresh water and then transferred to alkaline alcohol.

Early Development of Cidaris Tribuloides.

The living eggs of *Cidaris tribuloides* are exceedingly transparent. They may be fertilized readily in the laboratory with species sperm or with the sperm of other sea-urchins abundant in the region, among these being *Lytechinus variegatus* and *Tripneustes esculenta*, and the union of the male and female nuclei may be followed without difficulty. For straight fertilization the eggs were carefully washed and inseminated within a few minutes after their removal from the gonad.

The crosses are easily made. The eggs may be activated with the foreign sperm at once after their removal from the ovary, without artificial aid, although as a check against the possibility of error due

to chance fertilization with *Cidaris* sperm, they were kept for two hours before making the inseminations. A portion of the eggs was always kept as an unfertilized control. These statements regarding the ease of cross-fertilizing apply to conditions existing from March 5 through March 18, 1912, the only period in which I have had the opportunity of working on these forms.

In its normal development *Cidaris* proved of interest: (1) because of its slowness of development when compared with *Lytechinus* and *Tripneustes;* (2) in the difference in site of its mesenchyme formation; (3) in the place of appearance of the larval skeleton; (4) in the form of the larva.

Rate of Development of Cidaris compared with that of Other Echinoids.

Following fertilization, the various phases of the nucleus during division may be followed readily. The beginning of the anaphase of the first division is reached about 50 minutes after insemination. The cleavage is like that of the eggs of other echinoids, the formation of the micromeres being as in *Lytechinus* and *Tripneustes*. The blastula stage is reached in 16 to 18 hours, the eggs from a given female developing uniformly. The variation in rate of development of different lots of eggs is not altogether determined by temperature, since mixed lots of eggs, although nearly all may develop normally, do not develop at a uniform rate. Gastrulation begins in 20 to 23 hours; mesenchyme formation begins in 23 to 26 hours, the mesenchyme cells arising from the inner end of the archenteron; chromatophores appear in about 44 hours; the enterocœle arises as a single pouch in 44 to 50 hours; in 55 hours two enterocœles may be seen, formed by the division of the single vesicle; in 72 to 73 hours the first skeletal spicules may be noted.

Cidaris.	Hours.	Lytechinus.	Hours.
Blastulæ (swimming)	16 to 18	Blastulæ (swimming)	5.5
Gastrulæ (beginning)	20 to 23	Mesenchyme.....	8
Mesenchyme.....	23 to 26	Gastrulæ (beginning.)	9
Chromatophores.....	44	Chromatophores.....	15 to 16
Skeleton (beginning).	72 to 73	Skeleton (beginning).	15 to 16
Pluteus.....	120	Pluteus.....	24

Even at this time, the beginning of the fourth day, the body has not begun to assume the form of an echinopluteus, and it is not until the fifth day that the arms begin to push out. These facts are of interest when compared with those of the development of *Lytechinus*. Here the blastulæ reach a swimming stage in 5½ hours after the insemination of the egg; mesenchyme cells begin to push into the

blastocœle from the flattened and thickened posterior pole of the blastula in 8 hours; the process of gastrulation begins in 9 hours; chromatophores appear in 15 to 16 hours; skeletal spicules appear in 15 to 16 hours; and the young pluteus stage is reach in 24 hours after insemination; it may be reached in as short a time as 20 hours. These facts are shown in parallel columns (p. 6). The hours mentioned indicate hours after insemination. The difference in sequence of stages as well as the difference in rate of development is evident.

As has been stated above, there is nothing unusual in the development of *Cidaris*, aside from extreme slowness, until the stage when mesenchyme formation might be expected. The blastulæ (fig. 1*a*; plate 3, fig. F) have a wall of rather uniform thickness. The cells at the posterior end seem very slightly larger than those of other

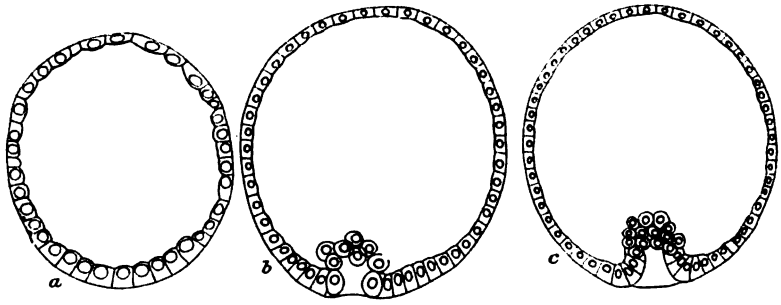

FIG. 1*a*, Optical section *Cidaris* blastula 16 hours old. Drawn from fixed and stained material. × 285.
1*b*, Optical section *Cidaris* beginning gastrulation; 20 hours. Drawn from fixed and stained material. × 285.
1*c*, Optical section *Cidaris* gastrula, 22 hours; drawn from fixed and stained material. × 285.

parts of the wall. A section of an 18-hour blastula (plate 3, fig. F) shows that these larger cells are about to move or be forced inward. The first indication of an archenteron appears in embryos of about 20 hours (fig. 1*b*). In these, at the posterior end, there may be seen a small, hollow plug of cells, extending into the blastocœle. The cells forming this plug are quite characteristically rounded, standing out distinctly from each other like the seeds in a blackberry. The cavity of the archenteron, though shallow, is cylindrical and has a distinct blastopore. The archenteron continues to grow forward into the blastocœle, and 3 hours later has about doubled in length (figs. 1*c*, 2*a*; plate 3, fig. G). The inner end is strikingly irregular in form, because of the protrusion of cells from its surface. No mesenchyme cells have as yet migrated from the wall of the archenteron, but sections (plate 3, fig. H) reveal the fact that they are in process of withdrawal at this time. The apparently loose contact of the cells of the arch-

enteron with one another is striking. There seems to be little surface tension in the wall at this time, each cell being rounded and having rather a minimal contact with its neighbors. Many of the cells are in phases of mitotic division. Slightly later, cells begin to move away from the outer surface of the archenteron and the conditions represented in plate 3, figures I and J, may be seen. The cells protrude long protoplasmic processes, which come into contact with one another and with the processes pushed out by adjacent cells; these then fuse and give rise to the characteristic networks which may be seen in echinoid gastrulæ (fig. 3*a*).

At about 50 hours the migration of mesenchyme has come to an end and the enterocœle arises as a single pouch from the inner end of the archenteron. On the left side this opens to the exterior through a dorsal water-tube (fig. 2*c*). The single enterocœle, about 5 hours later, divides into two, a right and a left, the left retaining connection

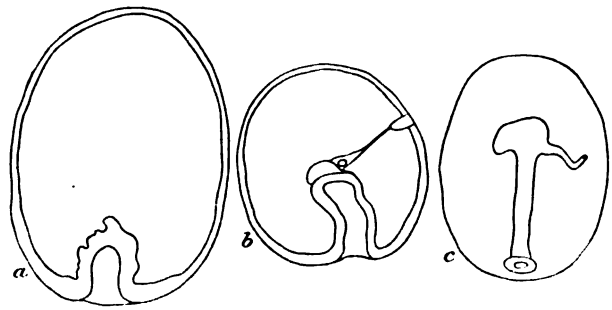

FIG. 2*a*, Optical section living *Cidaris* gastrula; 23 hours. × 180.
2*b*, Optical section living *Cidaris* gastrula; 30 hours. × 140.
2*c*, Optical section living *Cidaris* gastrula; 55 hours; enterocœle and pore canal present. × 140.

with the dorsal water-tube. By this time the wall of the archenteron has become thin, the cells composing it no longer standing out distinctly from each other.

About this time the spheroidal form of the embryo changes, due apparently in part to the more rapid growth of the dorsal region, which causes the blastopore to open on the ventral surface, and in part to the modification in form of the future oral area. The anal area remains rounded, while the oral area becomes first flat and then concave. A ciliated band appears along the posterior edge of the oral area. This is the posterior ciliated band. It becomes well established before there is any indication of an anterior ciliated band. The anterior band is present at 66 hours (fig. 4*a*). A stomodæal invagination appears about the seventieth hour and pushes back until it comes into contact with the future esophagus, the inner end of the archenteron having been directed toward the ventral side.

In some sections of embryos of an age of 73 hours the mouth opening does not seem to be established; in others the opening is present. It is therefore safe to say that the mouth opens about the beginning of the fourth day. The first appearance of skeletal spicules is about this time, these spicules arising in groups of mesenchyme cells at about the level of the outer ends of the posterior ciliated bands. As these rods increase in length, the sides of the embryo grow out to form what are probably the post-oral arms (figs. 4, *b* and *c*), the fenestrated rods in their growth keeping pace with the growth of the arms.

The cultures were kept under observation until the end of our stay at Montego Bay (two weeks). During this time no essential change in the form of the larva took place. The skeletal rods increased in

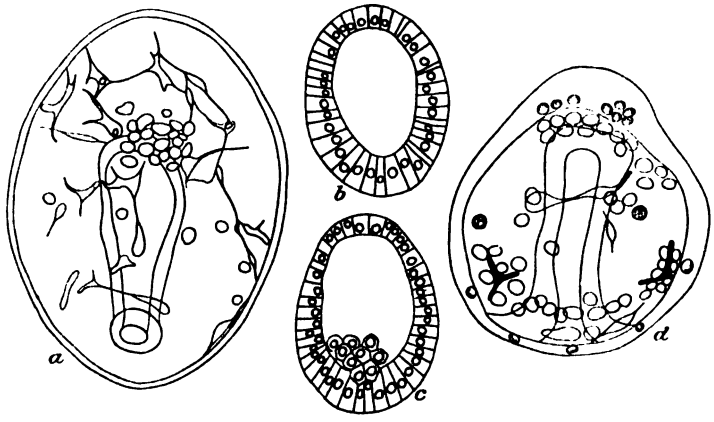

FIG. 3*a*, Optical section living *Cidaris* gastrula; somewhat flattened by pressure of coverslip; 41 hours; enterocœle forming; mesenchyme cells abundant in blastocœle. × 140.
3*b*, Section of blastula of *Lytechinus;* 6 hours; from fixed material. × 285.
3*c*, Section of blastula of *Lytechinus* with mesenchyme cells proliferating; 7 hours; from fixed material. × 285.
3*d*, Optical section living gastrula of *Lytechinus;* 20 hours. × 285.

length and the inner ends of these rods assumed a more definite association as a framework at the sides of and ventral to the stomach (fig. 5*b*). In the most advanced specimens that have been studied the fenestrated rods show as many as 14 openings, and there has been a pronounced increase in the length of the antero-lateral rods. The body-rods extend posteriorly on each side of the stomach, while the ventral transverse rods have grown toward the median ventral line, although there has as yet been no contact or union between the ends of the rods of opposite sides.

COMPARISON WITH OTHER INVESTIGATIONS OF CIDARIS.

Cidaris tribuloides, as may be seen from the foregoing description, is quite unlike the more familiar echinoids in the time and place of

formation of primary mesenchyme and in the form of the pluteus. The only detailed description I have found of the early development of a Cidarid is that of Prouho (1887) on *Dorocidaris papillata*. The rate of development of this form is very slow, slower than that which I have recorded for *Cidaris tribuloides*. The stage of the gastrula with a primary enterocœle is reached in 6 days; the enterocœle has divided to form two pouches in 8 days; while in 10 days skeletal rods with four openings are present. Prouho kept larvæ of this species alive for 3 months and obtained plutei with 3 pairs of larval arms and of the characteristic echinopluteus form.

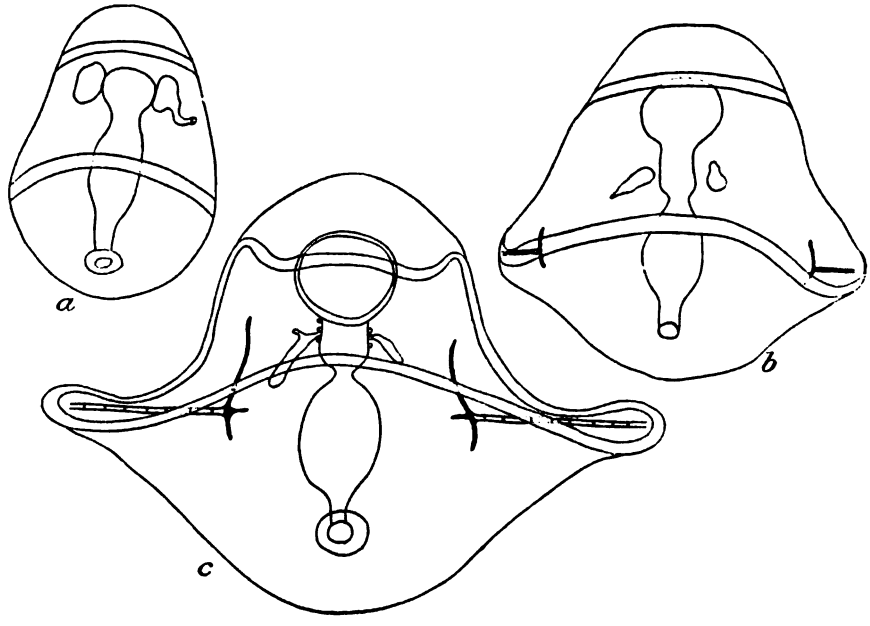

FIG. 4*a*, Free-hand sketch of living *Cidaris* larva in ventral view; 66 hours.
4*b*, Camera sketch of living *Cidaris* larva in ventral view; 73 hours. × 135.
4*c*, Camera sketch of living *Cidaris* larva in ventral view; 6 days. × 135.

Prouho's description of the process of mesenchyme formation is not complete enough to enable me to decide whether the process in these two Cidarids is identical. He describes the mesenchyme as budding into the blastocœle from the posterior wall of the blastula, and gives a figure illustrating the process. This figure would serve as a satisfactory illustration of beginning gastrulation, as I have seen it, in *Cidaris tribuloides*. Without question the first cells that are carried into the blastocœle in *tribuloides*, as invagination begins, are the future mesenchyme cells, but these cells do not leave their position in the wall of the archenteron until this has grown well toward the center of the blastocœle. The appearance is somewhat that of mass budding. It might be called such if the cells formed a

solid mass, but they form instead the inner end of the hollow archenteron. The compact mass of cells shown by Prouho in his figure causes me to believe that the manner of formation of mesenchyme in *Dorocidaris papillata* will be found, on reexamination, to be of the type that I have described for *Cidaris tribuloides*.

Mortensen (1921) has described observations that he made in 1915 on *Eucidaris thouarsi*. His figure of a larva 6 days old demonstrates that the *thouarsi* larva is very similar to the *tribuloides* larva. Mortensen (1921, p. 78 *et seq.* and appendix) has suggested that the very unusual larva that he has described as *Echinopluteus transversus* is really the *Cidaris* larva. The additional evidence presented in this paper supports, so far as it goes, Mortensen's suggestion. My oldest specimens have been reared for 2 weeks. None of these larvæ has reached the stage of development shown by Mortensen's plutei obtained from plankton samples from the West Indies and from the Indian Ocean. In my oldest or most advanced larvæ (fig. 5*b*) the fenestrated rods have increased noticeably in length and the anterolateral rods have extended well forward into the anterior end of the larva (fig. 5*a*). No contact between the ventral transverse rods of opposite sides or of body-rods has yet occurred.

Formation of Mesenchyme in Echinoderms.

The manner of formation of mesenchyme that I have described is similar to that occurring in *Antedon* as described by Seeliger, and which has been regarded as typical of Crinoids. Mortensen (1920), in his study of the development of the Crinoid *Tropiometra carinata*, has discovered that in this form, prior to the invagination of the wall of the blastula in the formation of the endoderm, there is a migration of cells into the cavity of the blastosphere, probably from different places in the wall of the blastosphere; "these cells lie loosely in the cavity and look like mesenchyme cells, which, however, they are not" (p. 8). When the cavity of the blastula is nearly full of these cells the typical invagination begins and the loose cells become closely applied to the upper end of the invagination. This process is in striking contrast to the condition in *Antedon*, in which Seeliger found no free cells in the blastocœle until after the invagination of the endoderm. Mortensen (1920), in his study of the development of one of the viviparous Crinoids, *Isometra vivipara*, found a cleavage of the kind typical of Arthropods; there is a division and migration of nuclei before any cell-walls appear; ectoderm and endoderm are differentiated in place, no invagination occurring. There are no cells in the space between ectoderm and endoderm, but some yolk grains may be seen lying in this cavity.

Guthrie and Hibbard (1919) have given a summary of the facts known regarding the time of formation of mesenchyme in the various

classes of Echinoderms. To the list given in the paper cited should be added Mortensen's contributions on Crinoids and that of Oshima (1918, 1921) on the Holothurian *Cucumaria echinata*, in which the mesenchyme cells are described as migrating into the blastocœle before the beginning of gastrulation.

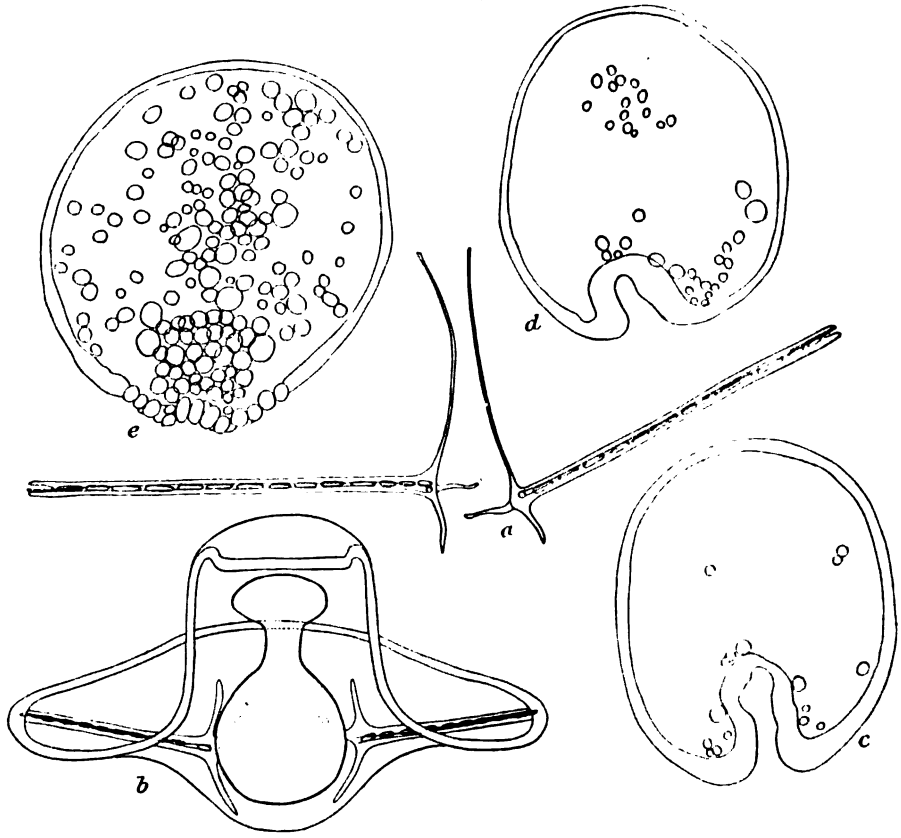

FIG. 5*a*, Skeletal rods from fixed and mounted *Cidaris* larva. 6 days. × 350.
5*b*, *Cidaris* larva, 2 weeks old, fixed and mounted. Camera sketch. × 110.
5*c*, Camera sketch of living *Cidaris* ♀ × *Lytechinus* ♂ gastrula. 24 hours. × 220.
5*d*, Camera sketch of living *Cidaris* ♀ × *Lytechinus* ♂ gastrula. 24 hours. × 220.
5*e*, Camera sketch of living *Cidaris* ♀ × *Lytechinus* ♂ gastrula. 40 hours. × 220.

Mortensen's (1920) studies have shown that there is diversity in the manner of formation of mesenchyme in the Crinoids, a fact which our knowledge of the development of three species of *Antedon* had failed to reveal. These observations do not affect the conclusions that I have drawn regarding the primitive nature of the development of *Cidaris*.

Cidaris tribuloides, in the estimation of those qualified to speak on the systematic position of echinoids, is primitive. This fact suggests

the probability, although it does not absolutely establish the proof, of the conclusion that the development of *Cidaris* is primitive.

Observations on the Hybridization of Cidaris.

At the time when these observations on the development of *Cidaris* were made, March 1912, two other sea-urchins in the region were breeding. These were *Lytechinus* (*Toxopneustes*) *variegatus* and *Tripneustes* (*Hipponoë*) *esculenta*. The fertilization of the egg of *Cidaris* by either *Lytechinus* or *Tripneustes* sperm was easily accomplished. No preliminary treatment of the eggs was necessary. It was possible to fertilize the eggs with either *Lytechinus* or *Tripneustes* sperm immediately after their removal from the ovary, but, as a precaution against failure to detect chance fertilization by *Cidaris* sperm, they were kept for 2 hours before inseminating with the foreign sperm. More than 90 per cent of the eggs so treated fertilized; the typical fertilization membrane appeared shortly after the addition of the sperm.

The reciprocal crosses were not readily made, and as the time available was short and the problem with which my investigation was concerned was not closely connected with that of specificity in fertilization, no attempt was made to develop a successful technique for these crosses.

In the cross-fertilized *Cidaris* eggs, no difference from the characteristic normal *Cidaris* development was noted before the beginning gastrula stage. The fertilization-cleavage interval was not lessened. Cleavage was regular; the micromeres were formed as in other echinoid eggs, and the blastulæ had the appearance of normal *Cidaris* blastulæ. In both crosses the mesenchyme cells arose from the sides and around the base of the archenteron, close to the point of union of the archenteron with the wall of the gastrula (plate 3, figs. A to E). In point of time the appearance of the mesenchyme seemed slightly hastened, although not sufficiently to warrant a general conclusion to that effect, as it was within the range of variation between different lots of straight fertilized eggs.

As to the place of mesenchyme formation, there is no chance for individual variation in the larvæ or in different lots of eggs to form the basis of an error in conclusion. In *Cidaris* gastrulæ the archenteron is a straight, slender tube, at whose inner end the migrating mesenchyme cells may be seen readily (plate 3, fig. J). At the time of the beginning of the formation of mesenchyme the gastrula is exceedingly transparent and the observer may convince himself that there are no formed elements at any place in the blastocœle. Figures 5, *c*, *d*, and *e*, are of optical sections of *Cidaris* ♀ × *Lytechinus* ♂ living gastrulæ. In these the primary mesenchyme cells may be seen clustered at the base of the archenteron and in some cases dispersed

throughout the blastocœle. In plate 3, figures A to E, sections of the posterior portion of embryos in process of gastrulation are shown. In plate 3, figure A, cells are in process of migration from the wall; in plate 3, figure B, mesenchyme cells are at the inner end of the archenteron and at its base. Figures C, D, and E of plate 3 are from the same slide and are all of embryos 24 hours old. They have been selected because they show considerable individual variation. In figure C of plate 3 no cells have left the wall of the archenteron; in figure D of plate 3, mesenchyme cells may be seen at the base of the archenteron; and in figure E of plate 3, mesenchyme cells are to be seen at the base of the archenteron and in process of withdrawal from its wall. It is of interest to compare these sections of the hybrids, age for age, with the sections of the normal larvæ. The corresponding ages are figure A of plate 3 with F and G, all 18-hour embryos; figure B with H, both 23-hour embryos; and figures C, D, and E with I, all 24-hour embryos.

Succeeding stages show considerable variation. In some the growth of the archenteron ceases and the blastocœle becomes filled with a mass of opaque cells (fig. 5*e*). In others gastrulation continues slightly beyond the stage indicated in figure E of plate 3. In a few cases a small triradiate spicule was found in the mass of mesenchyme cells at the right and left of the base of the archenteron. I was unable to keep the hybrid material alive beyond the gastrula stage. No plutei whatever were obtained.

It is at this stage of beginning gastrulation that many attempted hybridizations between species of Echinoids fail. The material from which sections represented in figures B to E of plate 3 were made enables us to see clearly that the failure in development is accompanied by an extreme degeneration of nuclei. In figure B the cells above the inner end of the archenteron seem to be in a process of disgorgement of chromatin; in the same figure a mesenchyme cell on the lower left side is shown which has completed such a process. In figure C two of the cells in the wall at the lower right are degenerating, while in figures D and E numerous stages in karyolysis are shown; the nucleus in some instances seems to have disintegrated, in others to have become simply a deeply stained mass of chromatin which may even be extruded from the cell. In some sections these distinct masses of deeply stained material may be found in considerable abundance among the scattered cells.

When we review this series of changes in the development of the hybrids and compare this development with the development of *Cidaris* and with the corresponding blastula and gastrula stages of *Lytechinus* (figs. 3, *b*, *c*, and *d*) and of *Tripneustes*, it may be seen readily that the processes of development in the hybrid are intermediate in character, lying between those of *Cidaris* and those of

Lytechinus and *Tripneustes*. In *Cidaris* the primary mesenchyme cells are given off from the inner end of the archenteron (figs. H, I, and J of plate 3); in *Lytechinus* and *Tripneustes* these cells arise from the posterior wall of the blastula (figs. 3, *b* and *c*), while in the hybrids they arise from the wall of the archenteron at the time this structure commences to grow into the blastocœle (figs. A, B, D of plate 3; figs. 5, *c* and *d*). The most striking result of fertilization with foreign sperm has been this change in the time and place of mesenchyme formation.

Influence of Spermatozoon on Production of Paternal Characters.

This result gives proof of an earlier visible evidence of the influence of the spermatozoon in the production of paternal characters than has previously been gained. The reason for this lies wholly in the nature of the material. By chance, material belonging to two visibly different systems of development was obtained.

In the discussion between Boveri and Driesch, in 1903–04, on this subject, evidence on the form of the larva, the skeleton, the number of chromatophores, the pigment content of the chromatophores, the arrangement of the chromatophores, the number of primary mesenchyme cells, and, under certain conditions, the size of the larvæ were considered. With the exception of the primary mesenchyme cells, these are, as events happen in early development, characters which are relatively late in the time of their appearance, and yet the visible differences in the material were not of sufficient value to enable Boveri and Driesch to reach a conclusion in common. The reason for this failure to reach such an agreement seems to lie in the fact that the forms used are closely enough related to have the same system of development, and any differences that could appear are comparatively minor ones.

If we consider the rôle of the spermatozoon in development, we find that the function of the spermatozoon may be double. It may give the initial impulse to development and carry the determiners for the development of paternal characters into the egg; or it may give this initial impulse without exerting influence in later differentiation.

The mature egg contains material whose differentiation will result in a new individual. Treatment with egg secretions, with a great variety of reagents, or the mere penetration of the surface of an egg by a spermatozoon, or by a sharply pointed instrument, may cause the egg to develop parthenogenetically into a thelykaryotic individual. The entrance of a spermatozoon, followed by the fusion of the sperm nucleus with the egg nucleus, may cause the egg to develop into an individual showing biparental characters. Usually we have thought of fertilization as comprising the whole series of changes occurring

during the time extending from the instant of contact of the spermatozoon with the surface of the egg to the completion of fusion of the germ nuclei, although we have tacitly admitted the logic of the position that fertilization is not completed until the conjugation of homologous maternal and paternal chromosomes. In practice, however, the word fertilization is often used as though it applied merely to the initial impulse to development.

Strictly speaking, the development of a uniparental individual begins with the separation from the primordial germ-plasm of the material which is to form the ovum from which the body of that individual is to be differentiated. All of the so-called stages in oögenesis are stages in the development of the individual. In biparental individuals there must be added the processes of formation of the spermatozoon which conjugates with the egg. Development may be slowed down, possibly even suspended, pending the activation of the egg as brought about by the earlier stages of union of the two germ-cells. Development then goes on as a continuous series of reactions, up to a certain point, difficult to ascertain but nevertheless actual, when the progressive differentiations in both body and mind, if one were to consider higher animals, come to an end. Development may be regarded as completed when progressive differentiation ceases and regressive changes set in.

The Spermatozoon and Fertilization.

For purposes of convenience in study and analysis, development is often considered as a series of definitely limited, consecutive stages rather than as a continuous process. Indeed, the course of development seems to fall rather naturally into periods, the beginning of each of these standing out as a critical point in the life of the organism. One of these periods begins with the activation of the egg to its development as a multicellular organism.

Lillie (1919, p. 129) says concerning fertilization: "It is a series of reactions which can not be regarded as complete until full capacity for development and inheritance is attained by the zygote." In his discussion of the physiology of the spermatozoon, Lillie distinguishes between cortical block to the fertilization reaction and internal block to later stages in fertilization. From my study of hybrid material I should like to go a little further in the characterization of stages, defining cortical block, as Lillie has done, as the block to the cortical reaction, but limiting the use of the term internal block to the period during which conditions which prevent the union of sperm and egg nuclei are effective, and adding developmental block as a designation of the block that may become evident after a successful activation of the egg and the union of the two germ nuclei. This block to development may operate at an earlier or a later period,

and we might distinguish between early developmental block and late developmental block. In the material described in this paper, and in much material of a similar nature, normal development stops at the beginning of gastrulation, even though there has been no evident failure in any of the processes of development up to that time.

It has been found possible to overcome cortical block by various preparatory treatments of the egg, and some success has been won in the search for methods of eliminating internal block, but little has been accomplished in the way of devising corrective methods for block of the later period.

Godlewski's (1911) method of treatment of *Sphærechinus* eggs after insemination with *Chætopterus* sperm is an excellent example of success in the elimination of internal block. Godlewski found it possible to activate the eggs with the foreign sperm. The fertilization membrane was formed, but no further development followed. After determining that development did not follow when unfertilized eggs were subjected to a short treatment with hypertonic sea-water, he found that if the eggs were first inseminated with the foreign sperm and then subjected to a treatment of 22 to 25 minutes with hypertonic sea-water, the sperm and egg nuclei united and the eggs continued to the pluteus stage. Following this union of the nuclei, the paternal chromatin was eliminated and the later development was in effect parthenogenetic. A similar method of treatment was not successful with *Sphærechinus* eggs inseminated with *Dentalium* sperm.

Cross-Activation versus Cross-Fertilization.

Among investigators in the field of experimental hybridization, there has long been dissatisfaction with the term "cross-fertilization," for the reason that it does not always describe the nature of the result obtained. The term may or may not be correctly applied. The phrase "attempt at cross-fertilization" does not remove the difficulty. If one speaks of successful cross-fertilization, the difficulty is even greater. In one paper (1911) I arbitrarily designated as "successful" those crosses that gave swimming gastrulæ. That was for the purpose of ruling out all cases which resulted in the development of irregular, formless masses of cells. Yet "successful fertilization" can not be a relative term. The only test of success in fertilization is in the production of fertile offspring. This might be called the eugenic test.

If we regard fertilization as the cortical reaction of the egg to contact with the spermatozoon, cross-fertilization would follow many inseminations, and the term "cross-fertilization," as used commonly in the biological literature of the present time, would not be incorrect.

If we define fertilization as the process of conjugation of egg and sperm nuclei, and stop there without further qualification, cases in which there is only a temporary fusion of egg and sperm nuclei, followed by the rejection of the paternal chromatin, might be accepted as examples of fertilization. If, however, we follow this definition to its logical conclusion and insist further that fertilization "can not be regarded as complete until full capacity for development and inheritance is attained by the zygote," or if we define fertilization as "the permanent fusion of two germ-cells, one of paternal and one of maternal origin" (Wilson, 1902), and give to this the necessary physiological qualification, there need be little difficulty in restricting the use of the term cross-fertilization to its proper signification.

The real difficulty does not lie in the use of the word "cross," but in the use of the word "fertilization." Suppose that in an attempted cross we get nothing more than activation. The eggs have then been "cross" activated.

The sperm nucleus having entered the egg, internal block may intervene to prevent its union with the egg nucleus, yet the egg may develop thelykaryotically. Or suppose that no internal block to the union of the nuclei exists, yet in succeeding stages some deviation from a successful course of development occurs, such as the elimination of chromosomes in the first or any succeeding cleavage, or a complete developmental block at the time of beginning gastrulation; in none of the cases has the egg been fertilized. It has been cross-activated, and in the cases mentioned three different results have followed this activation. On the other hand, cross-activation may be followed by a series of reactions whose sum total is perfect fertilization, judged by the standard of attainment of full capacity for development and inheritance.

For these different results the terms suggested by Günther Hertwig (1918), with a slight addition that I shall suggest, will be found useful.

Classification of Hybrids.

G. Hertwig classifies hybrids as true hybrids or orthonothi and false hybrids or pseudonothi. The true hybrids contain the full complement of maternal and paternal chromatin, while the false hybrids contain the maternal chromatin only, their development being therefore parthenogenetic. The true hybrids may be divided further into fertile individuals, sterile individuals, and misformed, pathological, non-viable individuals. The fertile and sterile individuals correspond to Poll's (1920 and earlier papers) tokonothi and steironothi. For the misformed individuals Hertwig suggests the name dysnothi.

The false hybrids are of two types, those with haploid nuclei and those with diploid nuclei, those of the second type differing from the

first in the fact that their chromosomes have doubled in numbers by reason of a monaster division.

This classification does not provide a place for individuals that have been obtained by cross-activation, and that have lost some, but not all, of their paternal chromosomes by a process of elimination. It is evident that such forms are not true hybrids, for they do not contain all of the maternal and paternal chromosomes; neither can they be regarded as false hybrids, since they contain some paternal chromosomes. For these individuals I suggest the name *partial hybrids*. It is conceivable that partial hybrids might be fertile, sterile, or misformed and non-viable. Evidence on these points is incomplete.

Our classification might then be:

1. True hybrids, all chromosomes retained: *a*, fertile individuals; *b*, sterile individuals; *c*, misformed, non-viable individuals.
2. Partial hybrids, partial elimination of paternal chromosomes: *a*, fertile individuals; *b*, sterile individuals; *c*, misformed, non-viable individuals.
3. False hybrids, maternal chromatin only retained; parthenogenetic: *a*, haploid nuclei; *b*, diploid nuclei.

Some of the misformed, non-viable, true, and partial hybrids, although they do not produce offspring, are potentially fertile, just as are the young, fertile, true hybrids that die before the age of maturity. In both cases failure to produce offspring may be regarded as accidental. The group of misformed, non-viable individuals in each class will contain sterile forms:

The whole matter may be stated in another way. It is only by the application of a performance test and by cytological examination that we can determine whether true cross-fertilization has taken place. The performance test lies in the production of fertile offspring. Cytological examination alone will enable us to determine whether any of the chromosomes have been eliminated. If only the maternal chromatin is retained, the individuals obtained from the cross-activated eggs will be false hybrids (pseudonothi). If both sets of chromosomes are retained, we shall have true hybrids (orthonothi), but if these hybrids should be sterile, sterile because of an inability to produce ripe germ-cells, these hybrids can not be regarded as having been formed from "fertilized" eggs. The egg was activated, no internal block prevented the union of the germ nuclei, developmental block did not occur until the time of expected maturity, but full capacity for development and inheritance was not attained.

Successful cross-activation lies in demonstrable cortical reactions in the egg. Granting that these reactions have taken place, and that internal block or early developmental blocks have been overcome, the cross-activated egg may give rise to sterile, or to misformed, non-viable, true hybrids. Poll (1920) points out the fact that

tokonothi may, by accident, be sterile, their sterility, however, not being due to a lack of ability to produce mature germ-cells.

Successful cross-activation may be followed by the fusion of the germ nuclei, but because of a partial developmental block some paternal chromosomes may be eliminated. Partial hybrids will be the result. Judged by the standard of full capacity for inheritance and development, and tested by cytological examination, even fertile partial hybrids fail to meet the fertilization test.

Finally, successful cross-activation may be followed by internal block to the fusion of the germ nuclei, and the paternal chromatin may be eliminated, but developmental block may fail to intervene to prevent development. The result of this activation will be the production of false hybrids. These hybrids, again, although they may be fertile, can not be said to have developed from fertilized eggs, since they have not the full capacity for development and inheritance nor have all of the chromosomes been retained.

PART II. THE CYTOLOGY OF THE EGGS OF CIDARIS TRIBULOIDES AND OF CROSS-ACTIVATED CIDARIS EGGS.

Structure of the Cidaris Egg.

The living eggs of *Cidaris* are about 0.07 mm. in diameter. They are very transparent and the various phases of the nucleus during division may be followed readily. Because of the transparency of the living egg, I was much surprised to find that in the stained sections the cytoplasm was filled with deeply staining spherules (plate 1, A to E; plate 2, A and B). As this seemed at first a somewhat unusual feature in a sea-urchin egg, sea-urchin eggs often being described as alecithal, a somewhat prolonged study of these spherules has been made. My conclusions concerning them have been reached in part indirectly, through the examination of other sea-urchin eggs which were available for study by the aid of various micro-chemical methods. My own study has been based on the eggs of *Arbacia punctulata*, *Echinometra mathœi*, *Peronella lesueri*, and *Salmacis alexandri*, while that of one of my students, Dr. Hope Hibbard, has been based on *Echinarachnius parma*.

The spherules in *Cidaris* measure from 0.2 to 2 microns in diameter. With iron hæmatoxylin they stain intensely black. During the resting stage of the nucleus the spherules are scattered uniformly through the cytoplasm from nuclear wall to the surface of the egg, the surface layer being filled with deeply staining microsomes. With the transition from the "resting stage" to the active phases of cell life as exhibited in mitosis—i. e., with the passage from the gel to the sol phase in the protoplasm—the spherules are carried out from the region of the nucleus, so that when the amphiaster is established it lies in a region of clear cytoplasm, one entirely free from the presence of the spherules described (plate 1, fig. A).

Some eggs are characterized by a smaller number of large spherules, other eggs by a larger number of smaller spherules. After the elimination of the possible explanation that the difference in size might be due to different degrees of extraction of the stain, an attempt was made to show a correlation between size of spherules and phase of division, a preliminary examination having shown that most of the eggs in the anaphase of the first division had large spherules. It was soon found that such a generalization would be without adequate basis in fact, since numerous exceptions to the supposed condition were found (plate 2, figs. D to L), and it may be stated positively that there is no correlation between the primary size of these deutoplasmic spherules and phase of division. As the

cleavage of the egg proceeds, there is a gradual diminution in size of the spherules, until in the gastrula all trace of them has been lost.

My conclusion regarding these spherules is that they are droplets of fat. In all of the sea-urchin eggs that I have been able to study by adequate methods I have found that in the clear protoplasmic matrix there are included, in addition to the so-called active inclusions, two types of inert bodies, fat droplets and yolk plates. The method of fixation used in preparing these *Cidaris* eggs for study is not adequate for the demonstration of the yolk plates, nor is it adequate for the demonstration of the fatty nature of the spherules described. These spherules, however, are in the nature of droplets, not platelets, and their distribution is similar to that of undoubted fat droplets in other sea-urchin eggs. Before making these supplementary studies I was inclined to the noncommittal description of these bodies as deutoplasmic spherules, but that, I now believe, would be in the nature of a rather unnecessary circumlocution.

The *Cidaris* egg is, as I have pointed out, unusual among echinoid eggs. A study of its protoplasm by modern cytological methods should prove of more than usual interest. My material was prepared for the study of chromosomes and has been satisfactory for that purpose. It is wholly inadequate for the study of cytoplasmic inclusions.

The fat droplets and yolk are shifted about readily in the protoplasm while this is in a sol phase. I have already described the movement of the droplets away from the nucleus during the early stages of division. A movement in the opposite direction begins as the egg passes from the anaphases to the telophases of division. While the chromosomes are developing into the usual chromosomal vesicles (plate 1, figs. C and E; plate 2, figs. F and G; fig. 25), there is a centripetal movement of the fat droplets, so that with the reformation of the nucleus these again lie distributed uniformly between the wall of the nucleus and the cell wall.

In some eggs, prior to the appearance of any constriction of the surface of the egg in division, there is a noticeable pressing together of spindle fibers along the line of future cleavage in the cytoplasm, and a very definite impression of internal cleavage is given (fig. B of plate 1).

The microsomes visible in the surface of the egg, as shown in figures A and B, plate 1, are of a nature differing from that of the fat droplets. They destain much more readily, and it will be noted that they are not shown in any of the remaining sections of the entire eggs. It will also be noted that these are the only sections of straight-fertilized *Cidaris* eggs shown, and that the other sections are of cross-activated eggs. I have considered very carefully the question of their abundance in one class of eggs and their scarcity in

another, and feel that the facts confirm the statement I have made. As to the nature of these granules, two possible explanations suggest themselves: Either they may be bodies containing material which enters into the cortical reaction alone in fertilization, in which case it would seem that there must have been a more complete reaction in the cross-activation than in direct activation, or (and this seems the more probable explanation) they contain the sperm-agglutinating substance described by Lillie, and a large part of this has been given up by the eggs during their two hours staling in sea-water before insemination. It should be a matter of little difficulty, if suitable material were available, to test the latter explanation by determining whether there is a progressive diminution in number of superficial granules in unfertilized eggs allowed to stand for some hours in sea-water. A positive proof of this point would not preclude the idea that their substance is also concerned in the reaction of the egg to the spermatozoon.

Study of Chromosomes in Species-Fertilized Cidaris Eggs.

The study of chromosomes both in the straight-fertilized and in the cross-activated eggs has been prolonged and has been based upon an abundance of material. Some evidence which has been of value has been obtained by the study of eggs in which development was initiated by Loeb's butyric-acid method.

The chromosomes in the straight-fertilized *Cidaris* eggs are crowded closely together; they are small and difficult to count. My study of the morphology of the chromosome groups has been mainly of sections showing polar views or of lateral views of the division figure in anaphase. In both types of section it is usually very difficult to distinguish between a fragment of a chromosome and an entire chromosome. In sections 5 microns in thickness, which pass through the spindle in the direction of its long axis, chromosomes will be found usually in three successive sections. Should the plane of the section be slightly oblique to the long axis of the spindle, there may still be chromosomes in three successive sections of the egg, but there will be only two sections of each anaphase plate. When the sections have been of this type I have combined the three sections in two figures, as in figures 7*a* and 7*b*, the latter containing the chromosomes from the first and third sections of the series. In such figures as this, therefore, sister chromosomes do not stand opposite each other in the anaphase plates as shown. The danger of overcounting the number of chromosomes in the longitudinal sections of the division figures because of the sectioning of individual chromosomes is probably offset by the fact that some of the chromosomes lie directly under one another and on this account may be overlooked, even in the most careful focusing.

From all the evidence obtainable I have concluded that the number of chromosomes present in these eggs is 37 and 38. This difference is due to the fact that half of the eggs contain a single V-shaped chromosome, this shape being due to the atelomitic attachment of spindle fibers, and the remaining half a pair of these V-shaped elements.

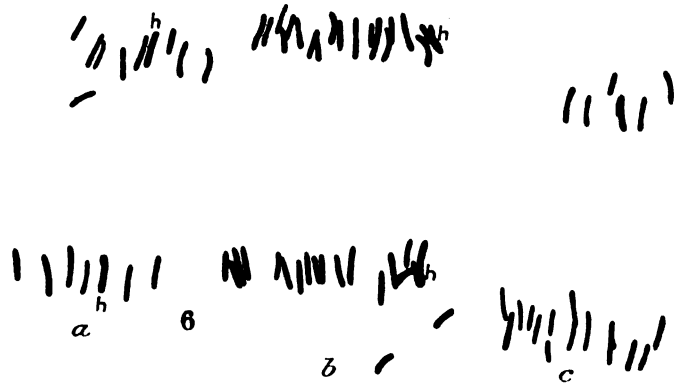

FIG. 6, *a*, *b*, and *c*. Three successive sections of a first-cleavage amphiaster, 35–41. Two heterochromosomes.

Figs. 6 to 11 are of anaphase plates from *Cidaris* × *Cidaris* eggs. The figures were drawn with the aid of a Zeiss compensating ocular 12 and 2 mm. oil-immersion objective. The camera sketches were enlarged 2 diameters and then compared with the sections and finished. These enlarged drawings have been reduced one-half in reproduction, so that the magnification of the chromosomes in the figures described is about 2,400 diameters.

FIG. 7, *a* and *b*. Plane of section was slightly oblique to long axis of spindle. Two sections have been combined in *b*. On the slide, the upper part of *b* appears in one section, then *a* as drawn, then the lower part of *b*. Two heterochromosomes, 33–34.

In most cases the arms of the V are brought so closely together, during their movement toward the poles of the spindles, that the chromosome has the appearance of a rod of twice the thickness of the remaining chromosomes. In one anaphase (fig. 11*a*) there is a single long chromosome; no V is present.

During division the yolk and oil droplets seem forcibly pushed out of the region of the amphiaster, which lies in a region of clear cytoplasm. As the cell passes into the telophases of division the yolk and oil droplets are carried inward and again lie distributed uniformly through the cell.

FIG. 8, *a*, *b*, and *c*. Three successive sections of a first-cleavage amphiaster. One heterotypic chromosome, 32–32.

FIG. 9, *a*, *b*, and *c*. Three successive sections of a first-cleavage amphiaster. Two heterochromosomes. One chromosome divided and lagging at the center. In the anaphase plates 32–32.

The chromosomes divide and move apart with great regularity; lagging chromosomes are seen only rarely (figs. 9*a* and 9*b*). Figures 6, 7, and 9 are of anaphase plates showing two of the double-armed rods in each plate of chromosomes; in figures 8 and 10 but one of these chromosomes of double width could be found. In figure 11*a* only one section of the spindle is shown; in this egg no chromosomes of double width could be found; there is, instead, a chromosome of

unusual length, which may be regarded as the heterochromosome, the probable explanation being that the attachment of the spindle fiber was telomitic rather than atelomitic.

In figures 11, *b*, *c*, *d*, and *e*, are shown polar views of anaphase plates; *b*, *c*, *d* are of the first division; *e* is one of the daughter plates of the second division. The chromosomes labeled *h* are those which I have

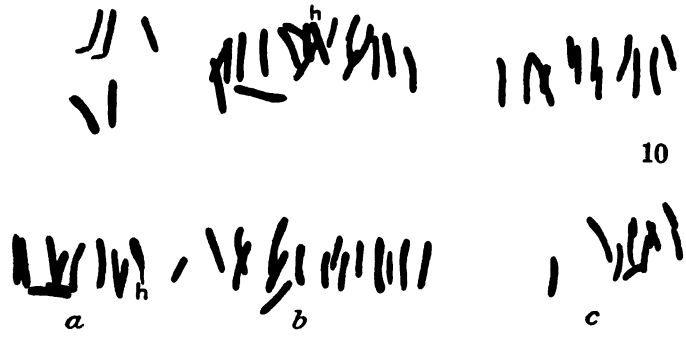

FIG. 10, *a*, *b*, and *c*. Three successive sections of a first-cleavage amphiaster. One heterochromosome, 36–38.

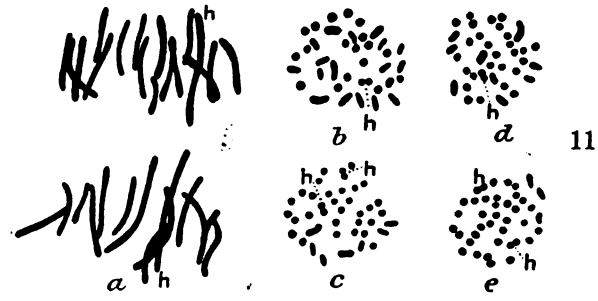

FIG. 11*a*, A single section from an amphiaster in which the chromosomes were much elongated. The extreme length reached by one of the chromosomes in each daughter plate may be seen readily.
11*b*, Polar view anaphase, first division 37 chromosomes.
11*c*, Polar view anaphase, first division 38 chromosomes.
11*d*, Polar view anaphase, first division 37 chromosomes.
11*e*, Polar view anaphase, second division 38 chromosomes.

interpreted as the heterochromosomes, while those which are separated slightly from each other I have regarded as autosomes. Reference to the figures of the lateral views of anaphase plates shows that in every plate there are several chromosomes which lie rather closely applied to each other. The reason for the presence of several slightly elongated chromosomes in each of these polar views will be seen readily when one visualizes the polar views of such sections as 8*a*. It will be seen at once that these, and similarly oriented chromosomes

in other plates, would appear in the polar view as short rods because of their oblique position. With this interpretation the number of chromosomes in these plates is either 37 or 38.

The final proof of these specific numbers of chromosomes in *Cidaris* was gained by a study of the eggs activated artificially. Unfortunately, in the material that I have studied I have been unable to find any amphiasters. The figures that show well are all of monaster plates. The most favorable of these is shown in figure 28. The chromosomes have all divided longitudinally on the monaster. Nineteen such divided chromosomes were present in one section, the remaining section of the egg containing no additional chromosomes. In this plate I am unable to designate the heterochromosomes with any degree of certainty; it may be one of either of the two rounded elements in the lower right-hand corner of the plate. The U- or V-shaped chromosomes may, however, be seen in most plates, as in figures 26 and 27*a*. Figure 26 was drawn from two sections. With the exception of two chromosomes, all were in one section. The total number of chromosomes here also was 19. In all sections in which the count could be made with certainty, 19 was the number of chromosomes present. Such figures as 27*a* and 27*b* are inconclusive as to numerical count, because of the evident fragmentation of the chromosomes in sectioning.

Chromosomes in Cidaris Eggs Cross-Activated by Lytechinus Sperm.

Cidaris ♀ × *Lytechinus* ♂.

Figures 12 to 17.

A comparison of figures 6 to 11 with figures 12 to 17 shows a general similarity in the character of the anaphase plates, but it also reveals some rather striking differences. As a rule, division seems to be rather regular, but even in the most regular figures some evidence of lagging in the separation of the chromosomes is evident (figs. 12 to 15). So far as the morphology of the chromosome groups is concerned, I have found that the eggs may be divided into two groups: one group in which each anaphase plate contains two of the V-shaped or broader chromosomes, and one group in which each anaphase plate contains three of these heterochromosomes.

In the preceding section evidence is presented that the *Cidaris* egg contains one of these heterochromosomes. It is therefore evident that the *Lytechinus* sperms are dimorphic, carrying either one or two V-shaped heterochromosomes. Figures 12, *a* and *b*, show two chromosomes of double width; figures 13, *a* and *b*, show three such heterochromosomes in each plate; figures 14, *a* and *b*, show three; figures 15, *a* and *b*, show three such chromosomes in the lower half of the figure and three in the upper half.

The evidence here confirms my conclusions reached in 1912, namely, that in *Lytechinus* (*Toxopneustes*) the fertilized eggs contained either 3 V's or 4 V's, and that this variation in number was due to the fact that the sperms were dimorphic with respect to these chromosomes, carrying either 1 or 2 V's into the egg.

Figs. 12 to 15 are of anaphase plates from *Cidaris* eggs activated with *Lytechinus* sperm. They were drawn and enlarged in the manner described for figures 6 to 11. They have been reduced one-half in reproduction. The magnification shown is of about 2,400 diameters.

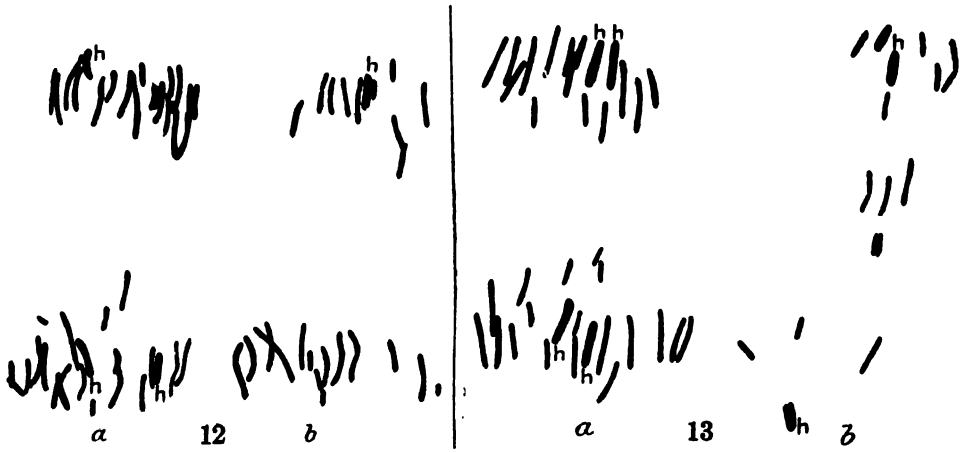

FIG. 12, *a* and *b*, *Cidaris* ♀ × *Lytechinus* ♂. Two heterochromosomes, 33–35.
FIG. 13, *a* and *b*, *Cidaris* ♀ × *Lytechinus* ♂. Three heterochromosomes. Much lagging; 28?–26?.

The fact that two heterotypic chromosomes in figure 15*b* lie among the lagging chromosomes, and the knowledge that two of these elements were brought into the egg by the *Lytechinus* sperm, make it seem probable that the lagging chromosomes are those of *Lytechinus*. The same type of evidence is given by the sections of the egg of which figure 17 is one. In the half of the spindle shown in figure 17 division is very regular and a V-shaped chromosome may be seen clearly in each plate. In the next section of the egg (not shown in the illustrations), two pairs of lagging V's lying among a very irregular and much twisted mass of autosomes may be seen, the evidence again lending support to the conclusion that the lagging chromosomes are those of *Lytechinus*.

The number of chromosomes in these plates varies greatly. In figures 12, *a* and *b*, the number is 33–35; in figure 13, 28?–26?; in figure 14, 27?–35?; in figure 15, 29–28. The expected number is 38–38 or 37–37. Figures 16, *a*, *b*, and *c*, are of a tetrapolar spindle in anaphase. While spindles of this type are usually associated with double fertilization, it is evident in this example that the chromosomes of but one

sperm nucleus are involved in division, and that of a sperm carrying but one heterochromosome. The expected number of chromosomes in this case would thus be 19+18=37; these have all split in division, which would give a total of 74. The number shown in the figure is 80, of which some are evidently fragments. One of the V's has been cut in sectioning. I am unable to designate its parts.

CHROMOSOMES IN CIDARIS EGGS CROSS-ACTIVATED BY TRIPNEUSTES SPERM.

Cidaris ♀ × *Tripneustes* ♂.

Figures 18 to 25.

In general, the division figures of this cross are more regular than those of the *Cidaris-Lytechinus* cross. There are some lagging chromosomes, but these do not form so striking a feature as in the preceding cross. Some of the sections show the heterochromosomes especially well. In figure 18, for example, 3 V-shaped and 1 hook-like chromosome are present; in figure 19, 3 V-shaped chromosomes

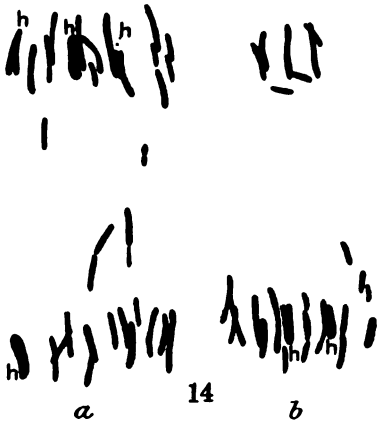

FIG. 14, *a* and *b*, *Cidaris* ♀ × *Lytechinus* ♂. Three heterochromosomes. Lagging chromosomes at center, 27?–35?

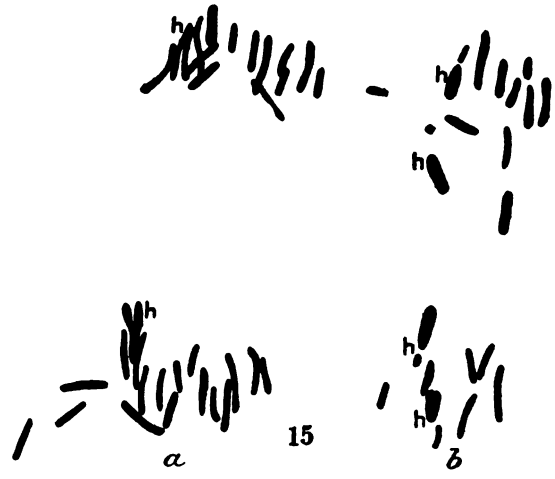

FIG. 15, *a* and *b*, *Cidaris* ♀ × *Lytechinus* ♂. The V-shaped form of the heterotypic chromosomes shows clearly 29–28.

were present in the egg, but no hook-shaped chromosome was present. These two illustrations represent the two classes of eggs that were present in these cultures. In figures 20, *b* and *c*, 3 V's; in figures 21, *a* and *b*, 3 V's and a hook; in figures 22, *a* and *b*, 3 V's; in figures 23, *a* and *b*, 3 V's and a hook. The sections from which figures 24, *a* and *b*, were drawn are of more than usual interest. Most of the chromosomes appearing in *b* are longitudinal sections of the chromosomes shown in *a*, as indicated both by position and width of the chromosomes. The third section of this spindle (not shown in the illustrations) contains a much involved mass of chromosomes, which

obviously could not have divided normally. The edge of this mass of chromosomes lies between the anaphase plates in figure 24*b*.

Here again the morphology of the groups of chromosomes confirms the expectation based on our knowledge of the chromosomes in *Tripneustes* (*Hipponoë*). From the studies of Tennent (1911*a*) and Pinney (1911) we know that the dimorphism in straight-fertilized eggs of *Tripneustes* is due to dimorphism of the groups of chromosomes in *Tripneustes* sperms, the sperms of this species introducing either 2 V's or 2 V's and a hook into the egg.

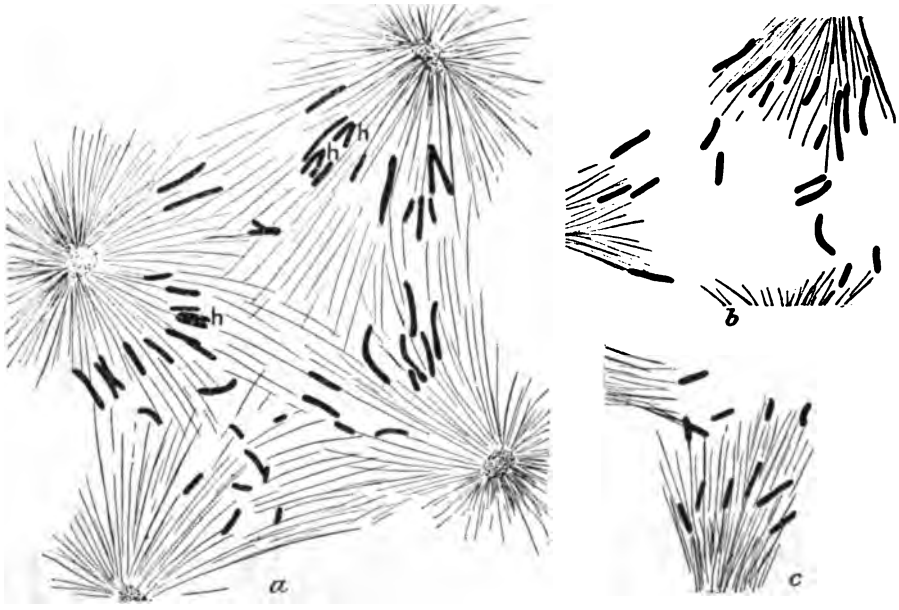

FIG. 16, *a*, *b*, and *c*, *Cidaris* ♀ × *Lytechinus* ♂. Three successive sections of a tetrapolar spindle 80 chromosomes, inclusive of fragments. × 2,400.

The expectation as to number of chromosomes in the cross-activated eggs is 19+16=35, or 19+17=36. The realization as to the number of chromosomes in the sections drawn is: Figures 20, *a*, *b*, and *c*, 38–35; 21, *a* and *b*, 25–34; 22, *a* and *b*, 29–28; 23, *a* and *b*, 22–26. It is evident that success in division of the chromosomes in the cross-activated egg is relative. Figures 20, *a*, *b*, and *c*, show a normal division. It is evident that at least two of the rods in the upper anaphase plate are fragments of chromosomes; probably a third is also a fragment. With the rejection of three, the count would be 35–35, the expected number following fertilization by the sperm carrying 2 V's only. In figure 21, the plane of section is slightly oblique to the long axis of the spindle. I do not feel confident that I have been able to see all of the chromosomes which are massed

in the upper plate in figure 21*a*. In figure 22, 6 or 7 chromosomes have been eliminated; in figure 23, 9 or 10; while in figure 24 indications are that nearly all of the paternal chromosomes were in process of elimination.

The amount of chromatin in the Zwischenkorper seems to vary (compare plate 1c with plate 2B), which may mean that a greater

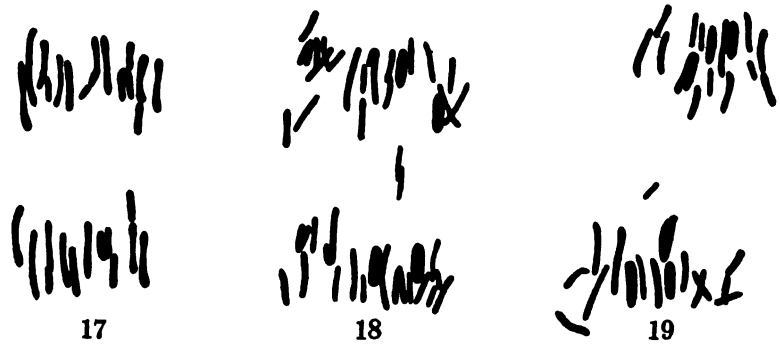

FIG. 17, *Cidaris* ♀ × *Lytechinus* ♂. V-shaped heterochromosome readily seen. × 2,400. Figures 18 to 24 are of anaphase plates from *Cidaris* eggs inseminated with *Tripneustes* sperm. They were prepared in the manner described for the figures 6 to 11 and reproduced at a magnification of about 2,400 diameters.

FIG. 18, *Cidaris* ♀ × *Tripneustes* ♂. A section selected because it contains all of the heterochromosomes, three V's and one hook, in each anaphase plate.

FIG. 19. *Cidaris* ♀ × *Tripneustes* ♂. Section showing three V's in each plate; no hook.

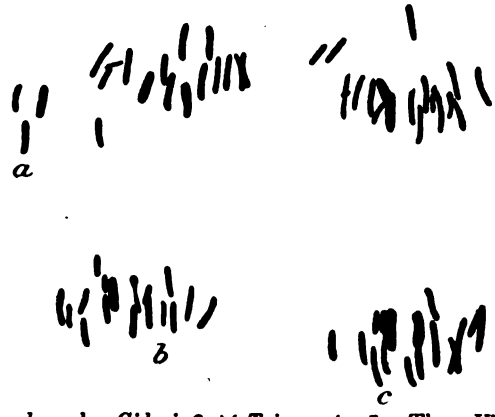

FIG. 20, *a*, *b*, and *c*, *Cidaris* ♀ × *Tripneustes* ♂. Three V's, 38–35.

amount of eliminated chromatin is included in some bodies than in others. Plate 2B was drawn from a preparation in which the process of destaining had been carried further than in that from which plate 1c was drawn. In addition it will be seen that figure B of plate 2 represents a stage of completed division. Figure A of plate 2 shows

lagging chromosomes which will be at the line of division of the cell and which will lie at the position of the Zwischenkorper.

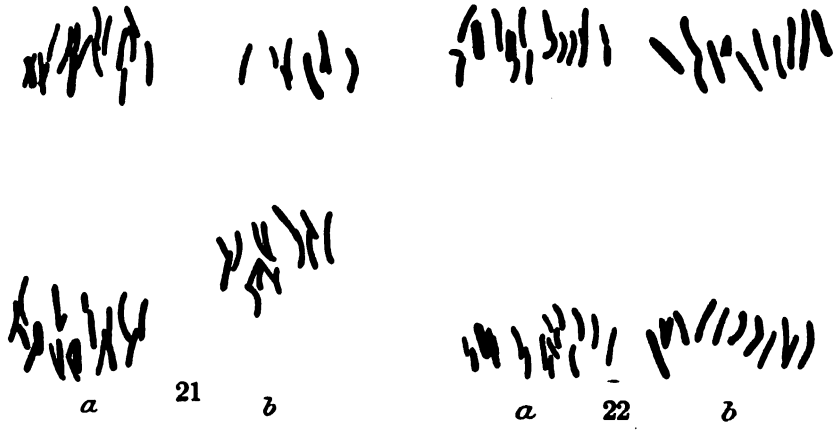

FIG. 21, *a* and *b*, *Cidaris* ♀ × *Tripneustes* ♂. Two V's and hook, 25–34.
FIG. 22, *a* and *b*, *Cidaris* ♀ × *Tripneustes* ♂. Three V's, 29–28.

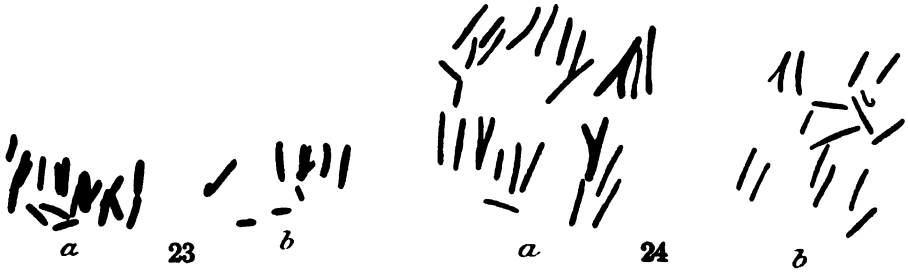

FIG. 23, *a* and *b*, *Cidaris* ♀ × *Tripneustes* ♂. Two V's and hook, 22–26.
FIG. 24, *a* and *b*, *Cidaris* ♀ × *Tripneustes* ♂. Early anaphase; the position and width of the chromosomes in *b* give clear evidence that these are merely sections of those shown in *a*. Two V's.

ELIMINATION OF CHROMOSOMES.

In 1912 I summarized the facts regarding retention or elimination of chromosomes in cross-activated Echinoid eggs as follows:

(1) Elimination of no chromosomes and dominance of one species over the other with respect to the character of the skeleton.
(2) Elimination of part of the chromosomes and dominance of one species over the other with respect to the character of the skeleton.
(3) Elimination of no chromosomes and skeleton of intermediate character.
(4) Elimination of part of the chromosomes and skeleton of intermediate character.
(5) Elimination of part of both maternal and paternal chromosomes and inhibition of development.

In group (2) I included such cases as result from the activations of the Echinoid egg by the sperm of annelids and mollusks (Godlewski, 1911; Kupelwieser, 1906) and the fertilization of eggs which had been given a certain impulse to parthenogenetic development by means of chemicals, which give, as these authors have pointed out, thelykaryotic larvæ. I stated further that, practically, larvæ derived from such crosses inherit from the egg parent alone just as strictly as if the eggs had been caused to develop from the first by artificial chemical fertilization. They are false hybrids.

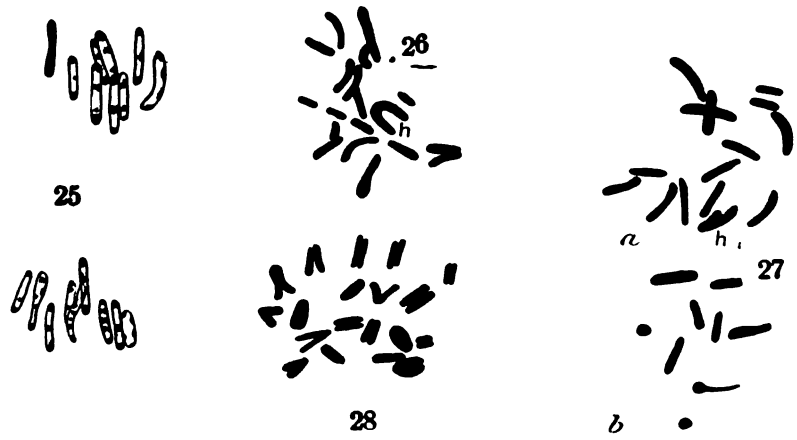

FIG. 25, *Cidaris* ♀ × *Tripneustes* ♂. Median section of three, other two not shown, showing chromosomes becoming transformed to chromosomal vesicles before contraction of chromosome has taken place. × 2,400.
FIG. 26, Parthenogenetic *Cidaris* egg. Prophase of monaster division. × 2,400.
FIG. 27, *a* and *b*, Parthenogenetic *Cidaris* egg. Two successive sections of monaster plate. Many elements shown in *b* are sections of those shown in *a*. × 2,400.
FIG. 28, Parthenogenetic *Cidaris* egg. Monaster division. All chromosomes have divided; 18 pairs. × 2,400.

These *Cidaris-Lytechinus* and *Cidaris-Tripneustes* crosses considered in this paper constitute another group.

(6) Elimination of part of the chromosomes, presumably paternal and failure in development.

These may be regarded as partial hybrids. Probably several additional crosses that have been made, but which have not received adequate cytological examination, will ultimately be found to belong in this group.

In these crosses, development seems to proceed well as long as the generalized type of development, common to each, continues; developmental block occurs when the period of specialized development begins. The egg seems unable to accommodate itself fully to the impulse for a divergent type.

Alteration in Physical Characteristics of the Cytoplasm of the Egg by Action of Foreign Sperms.

In my interpretation of the phenomena exhibited in the development of *Cidaris* and its hybrids I have been influenced, to a considerable extent, by the consideration of facts concerning the transformation of deutoplasmic materials to cytoplasm. The *Cidaris* egg, despite its transparent character, contains a relatively large amount of yolk and fat. This material gradually disappears as development continues.

I have also been guided by results which I have obtained from another inter-ordinal cross, *Arbacia* × *Moira* (Tennent, 1920). It is unnecessary to review in this place the facts presented in that paper, and it seems sufficient to say that certain granules and rods, present in sections of cross-activated eggs and absent in sections of straight-fertilized eggs, were explained as coarse precipitates formed as a result of the emission of a foreign enzyme from the nucleus. Even though we were to regard these bodies as artifacts produced by the fixing fluid used (acetic-sublimate)—for we know that certain metallic salts may cause the precipitation of proteids—the fact remains that physical conditions in these eggs must have been different than in the straight-fertilized eggs which were fixed at corresponding stages and in the same fixing fluid, and which show no bodies of this kind.

In continuation of the investigation mentioned above, one of my students, Miss Hibbard, has made a study of *Tripneustes* eggs fertilized with *Lytechinus* sperms, comparing these with the straight-fertilized and parthenogenetic eggs, and has found that in the cross-activated eggs which are developing normally granules appear and later disappear as the nucleus passes into the later phases of division. Here, again, the only explanation seems to lie in the action of the enzyme introduced by the foreign spermatozoon. Miss Hibbard has also determined that some of the cross-activated eggs, which segment less normally, show other and characteristic changes in their cytoplasm. These changes are clearly pathological.

The most striking result of the removal of cortical block followed by cross-activation that has come within my experience is that following the insemination of the *Lytechinus* egg, after preliminary treatment with NaOH or CaCl, with the sperms of *Holothuria floridana* (Tennent, 1911, p. 140). In this instance the sperm, upon entering, in most cases tears the egg to pieces. A deep notch or pathway made by the sperm may be seen and then the egg suddenly disintegrates. In other cases the entrance of the spermatozoon is followed by a slower, but none the less complete, cytolysis of the egg.

Gray (1913) studied the eggs of *Echinus acutus* fertilized by the sperm of *Echinus esculentus* and species-fertilized eggs of *Echinus*

acutus treated by hypertonic solutions. The results were similar. There was an elimination of a certain number of chromosomes from the nucleus in both the cross-activated eggs and in the straight-fertilized eggs which had been treated with hypertonic solutions. The eggs of *Echinus esculentus* were not affected by similar treatment.

Gray suggests, tentatively, after consideration of the results of McClendon (1913) and R. S. Lillie (1909, 1911), on increased permeability of the egg membrane after the entrance of the spermatozoon, that the degree of change in permeability after fertilization is a function of the sperm and that the cytological behavior of reciprocal crosses is explicable on this hypothesis. Gray points out that changes in permeability of the cytoplasm as induced by the sperm can not be a sufficient explanation of all abnormalities observed in cross-fertilized eggs.

Doncaster and Gray (1913), in considering the probable fact that the vesicles in the eggs of the cross *acutus* × *esculentus* are derived from the *acutus* chromosomes, suggest that the explanation may lie in an alteration of the permeability or osmotic condition of the egg, consequent upon the development within it of a foreign spermatozoon, i. e., the physical condition of the cytoplasm is altered by the development within it of a foreign sperm nucleus.

Nuclear Enzymes and Cytoplasmic Substrate.

The study of a sufficient number of species, both closely related and widely separated, has now given, I believe, an adequate basis for generalization.

The egg contains the mechanism necessary for development. It may develop parthenogenetically, giving a maternal larva and adult. In that development there is a harmonious interaction between the nuclear and cytoplasmic material. The results of cross-activation in which there is a complete rejection of paternal nuclear material and production of false hybrids, as in the Echinoid-Mollusk, or Echinoid-Annelid cross, are closely related to examples of artificial parthenogenesis.

Above this level there are crosses showing maternal or paternal influence in lesser or greater degree. We might pass in review a great number of cases of partial hybridization and reach finally undoubted examples of true hybridization.

If we restate these facts on the basis of chromatin content, we find that in false hybrids there is a complete elimination of paternal chromosomes, in partial hybrids a partial elimination of chromosomes, and in true hybrids no elimination of chromosomes.

The fact that the results obtained from a given cross differ from those obtained in the reciprocal cross indicates that the differences are not due to lack of harmony between the substances of the germ

nuclei. It is clear that cytoplasmic differences must be taken into account. The life of the cell lies in the interaction between nucleus and cytoplasm. The relative importance of each is that of enzyme to substrate. There can not be cytoplasmic control, nor can there be nuclear control, purely as such, for the processes of life lie in the interaction of both. There is nuclear control in that by the introduction of enzymes we obtain synthetic products; there is cytoplasmic control in that with a given substrate we provide material from which products are synthesized.

From the evidence given by *Arbacia-Moira* material (Tennent, 1920), it seems clear that the reactions in the cytoplasm caused by foreign sperms are unlike the reactions caused by species sperms. That fact fixes the attention on the nature of the activities of the nucleus.

The Binuclearity Hypothesis.

Various binuclearity hypotheses, founded in part on Richard Hertwig's chromidial hypothesis, have influenced interpretations of nuclear phenomena. The nucleus shows two phases, an active and a resting. These two phases, kinetic and interkinetic, have been made to lend themselves to an analogy with a true binucleate condition and to an assumption of dichromaticity. Of these two kinds of chromatin, one is supposed to be propagatory (idiochromatin), in evidence at the time of cell division; the other trophic (trophochromatin, somatochromatin), formed by the idiochromatin, but resident in the cytoplasm. The somatic phase of the nucleus covers a period during which it may be assumed that nuclear enzymes have passed from the nucleus into the cytoplasm, and the cytoplasm has become the seat of synthetic activities. The nucleus at this time is in a "resting" condition; it seems comparatively empty, is acidophile, and basophilic bodies may be found in the cytoplasm. Under the influence of the chromidial hypothesis, supposed particles of chromatin in the cytoplasm have been interpreted as chromidia, or as trophochromidia. The basophilic bodies found in cross-activated *Arbacia* eggs might have been interpreted similarly had there been any evidence that they were emitted from the nucleus. The possibility of the emission of large particles is foreign to our conception of the nature of the nuclear membrane.

DISCUSSION.

Masing (1910), selecting for study one of the nuclear constituents, nucleic acid, found that while during development in *Arbacia pustulosa* up to the blastula stage there is an increase of about a thousand fold in nuclear mass, there is no perceptible increase in the nucleic-acid content of the egg. He reached the conclusions that the nucleic acid of the cleavage nuclei arises from a preformed stock in the egg plasma and that nucleic acid and the chromatin of the histologists must be different things. (Quoted from Godlewski, 1911.)

During the period studied by Masing there has been no increase in the mass of organism. Godlewski (1908) showed that the total volume of plasma in the blastula is about one-third less than in the unsegmented egg. The nuclear material has increased in volume at the expense of the cytoplasm. Godlewski's investigations show a change in ratio between cytoplasm and nucleus from 550:1 in the unfertilized egg to 6:1 in the blastula. In the light of the results of Conklin (1912) on the growth of protoplasm during cleavage, and in the light of my own results from a study of the eggs of *Arbacia punctulata*, as yet unpublished, and of those of Hibbard on the eggs of *Echinarachnius parma*, in press, these figures need some revision. This revision will not affect Godlewski's general conclusions. The unpublished results mentioned above show that in the eggs of *Arbacia punctulata* and *Echinarachnius parma* there is a considerable mass of deutoplasmic material, which is in process of transformation to cytoplasm during the cleavage stages. In the echinoderm egg, despite its frequent transparent character, there is a stock of yolk and fat. Cell volume in these eggs is not equivalent to cytoplasmic volume. The growth in nuclear mass is due, in part at least, to the assimilation of deutoplasm.

Marcus (1906) and Erdmann (1908) have shown that the size of the chromosomes diminishes during cleavage. Erdmann has concluded that the chromosomes of the pluteus of *Strongylocentrotus* have only about one-fortieth the volume of those of the first cleavage spindle. She has also determined that there is a constant increase in total quantity of chromatin. Her figures show that at the stage of the blastula without mesenchyme, which Godlewski has estimated as a 1,256-cell stage, the chromosomal volume is 78 times greater than it was at the time of the first division. This would amount to an increase of about 6 per cent with the division of each cell. Godlewski (1908) estimated that the total volume of nuclear material is 47 times greater in the 1,256-cell stage than in the unfertilized egg, which would be 23.5 times the total volume in the fertilized egg. Inasmuch as he believed that practically all of this growth took place between the 1-cell stage and the 64-cell stage, and that but little increase of

nuclear mass occurred between the 64-cell stage and the blastula stage, this would mean an increase of about 37 per cent with the division of each cell. Godlewski speaks of the increase as being nearly in a geometric ratio, this calculation being based on the volume of nuclear mass in the unfertilized egg. It should be noted that Erdmann's figures are of volume of chromosomes and that Godlewski's are of nuclear volume. Conklin (1912) has estimated that in *Crepidula* the chromosomal mass grows at the rate of 8 per cent for each division up to the 32-cell stage.

Baltzer (1909) has indicated the large probable error in estimates of total chromatin volume that are based on the assumption that the chromosomes in an Echinoid egg are of equal size.

Mathews believes that nucleic acid is the chromatin of the histologists. We have seen that Masing found no evidence of increase of nucleic acid during development in *Arbacia* up to the blastula stage. The evidence of Conklin, Erdmann, and Godlewski is conclusive in its demonstration of increase of total volume of chromosomes during this period. If there has been no increase in the amount of nucleic acid, there must have been increase in its basic protein portion.

Goldschmidt's (1917) idea that the chromosomes act as adsorbents of enzymes which constitute the chemical basis of heredity finds much to support it in the facts demonstrated in this paper. We are able to show the presence of nucleic acid by our stains; we have no means of making the nuclear enzymes visible. Our only test for them is in the things that they do. We can not hope to demonstrate consecutive stages in processes of synthesis by specific stains. We can demonstrate, and the material discussed in this paper has demonstrated, the fact that foreign nuclear material produces reactions in the cytoplasm that do not occur in straight-fertilized eggs.

Closeness of relationship is by no means indicative of the readiness with which the initial impulse to development may be received, nor a sure criterion of the extent to which it may proceed. In the *Cidaris-Lytechinus* and *Cidaris-Tripneustes* crosses under consideration there seems to be little cortical block to the entrance of the spermatozoon. There is little internal block during early development. Development proceeds regularly to the period immediately before gastrulation. To this point it has been following the general path of development taken by most Echinoderms. At the point of deviation of special from general, abnormalities appear. Development ends in the gastrula stage, as in many crosses between Echinoderms. The cells which should have gone to the completion of the archenteron and the prospective mesenchyme cells are the first to die. Sections show the nuclei to be swollen with chromatin. The nuclei finally burst, extruding irregular masses of chromatin into the cytoplasm.

Developmental block in this case seems to be associated with what might be described as nuclear indigestion. Fulton (1921, p. 167), in describing the result of continued stimulation of a muscle on its nucleus, says: "With continued stimulation the nucleus must literally become overwhelmed with material to be oxidized; as a result, it would become fatigued, and would no longer be capable of performing its normal functions."

The word "overwhelmed" describes vividly the conditions involving the nucleus in these hybrids.

From the *Arbacia-Moira* material, the evidence obtained was interpreted as showing that enzymes are emitted through the nuclear membrane and that changes occur in the protoplasm following this emission. The materials formed pass back to and are taken into the nucleus. There is no evidence that the emitted material is chromatin.

There is nothing in these views that detracts from the chromosomal theory of inheritance. It is evident that what is transmitted from generation to generation is a course of development—what Brooks in "The Foundations of Zoology" calls a "capacity for nurture."

The results of these cross-activations show that an orderly series of developmental reactions may be disorganized by the introduction of foreign nuclear material. In the cross-activated eggs, in the interaction between nucleus and cytoplasm, the nucleus seems to be provided with more material than it can handle. In straight-fertilization the accumulation of product would have checked the action of enzymes before that condition arose. The foreign enzymes are specifically different and their action is not checked until a greater than normal supply for this egg has accumulated. Even though the nucleus may take care of products formed, development may come to an end because of an actual exhaustion of substrate.

SUMMARY.

Part I.

1. *Cidaris tribuloides* is a primitive Echinoid whose early development is less modified than that of the more modern Echinoids.

2. In its normal development it is of interest (1) because of the slowness of its development when compared with *Lytechinus* and *Tripneustes*, (2) in the difference in site of the formation of its mesenchyme, (3) in the place of appearance of the larval skeleton, and (4) in the form of the larva.

3. The eggs of *Cidaris* are activated easily by the sperms of *Lytechinus* or *Tripneustes*. These give interordinal crosses.

4. The larvæ obtained from such cross-activations die in the gastrula stage.

5. Cross-activation with these foreign sperms causes mesenchyme cells to pass into the blastocœle before the beginning of gastrulation, while in the species-fertilized eggs immigration of mesenchyme cells does not occur until after the archenteron has been formed.

6. It is suggested that the use of the term internal block be limited to block, or inhibition of the conjugation of the germ nuclei, and that the term developmental block be used in designating later inhibitions of development.

7. The use of a modification of the Günther Hertwig classification of hybrids is suggested.

Part II.

1. The eggs of *Cidaris*, although transparent, are rich in fat and yolk.

2. A study of species-fertilized eggs shows that half of the eggs contain 37 chromosomes and half 38. Eggs of the group containing 37 chromosomes have one V-shaped element, while those of the group containing 38 chromosomes have two V-shaped elements.

3. Parthenogenetic eggs have 19 chromosomes.

4. *Cidaris* sperms are dimorphic, half containing a V-shaped chromosome, half being without this element. Half of the spermatozoa contain 19 chromosomes, half contain 18.

5. Some of the paternal chromosomes lag in division and are eliminated during cleavage in cross-activated eggs.

6. Investigations on *Lytechinus-Tripneustes* and *Arbacia-Moira* material show alteration in the physical characteristics of the cytoplasm of the egg by action of the foreign sperm.

7. The phenomena exhibited suggest that the effects are due to the action of foreign enzymes on the cytoplasmic substrate.

8. The nucleus in cross-activated *Cidaris* eggs seems to be supplied with more material than it can utilize.

9. The facts suggest an emission of enzymes rather than an emission of chromatin.

10. The results show that in the cross-activated *Cidaris* eggs an orderly series of developmental reactions is disorganized by the foreign nuclear material at the time when divergence of two systems of development occurs.

11. Through its organization and in its capacity as substrate the egg fixes the course of development.

CONCLUSIONS.

The consideration of the facts established during the study of the material which has formed the basis of this paper gives a deep impression of the fundamental fact of organization. It gives additional proof of the existence of an underlying basis for development, which we may be able to distort, but which we are not yet able to shape at will.

The normal development of the *Cidaris* egg is of a less-specialized type than that of the eggs of the species whose sperms were used in the cross-activations. As long as the two courses of development lie parallel, we say that development is normal. When the point of divergence between the two paths is reached, characters appear which we call aberrant. Differentiation lies in a series of reactions between nucleus and cytoplasm. In attempting to superimpose a specialized on a non-specialized type of development we fail, because of our lack of ability to harmonize two disharmonious systems of development.

The consideration of this material emphasizes again the fact that the thing inherited by offspring from parent is the capacity for development. What that development will be depends on the interactions between nucleus and cytoplasm and on adjustment to environment. The cytoplasm is the material that is shaped during the series of reactions. It is because of the fact that the cytoplasm of the egg is the material basis of the body that Conklin's statement that the egg cytoplasm "fixes the general type of development" is true.

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ILLUSTRATIONS.

PLATE 1. All of the figures on this plate were drawn with a Zeiss compensating ocular 8 and 2-mm. immersion objective, giving a magnification, when drawn with a camera lucida on an inclined drawing-board slightly above table level, of about 1,800 diameters. These figures have been reduced one-half in reproduction.

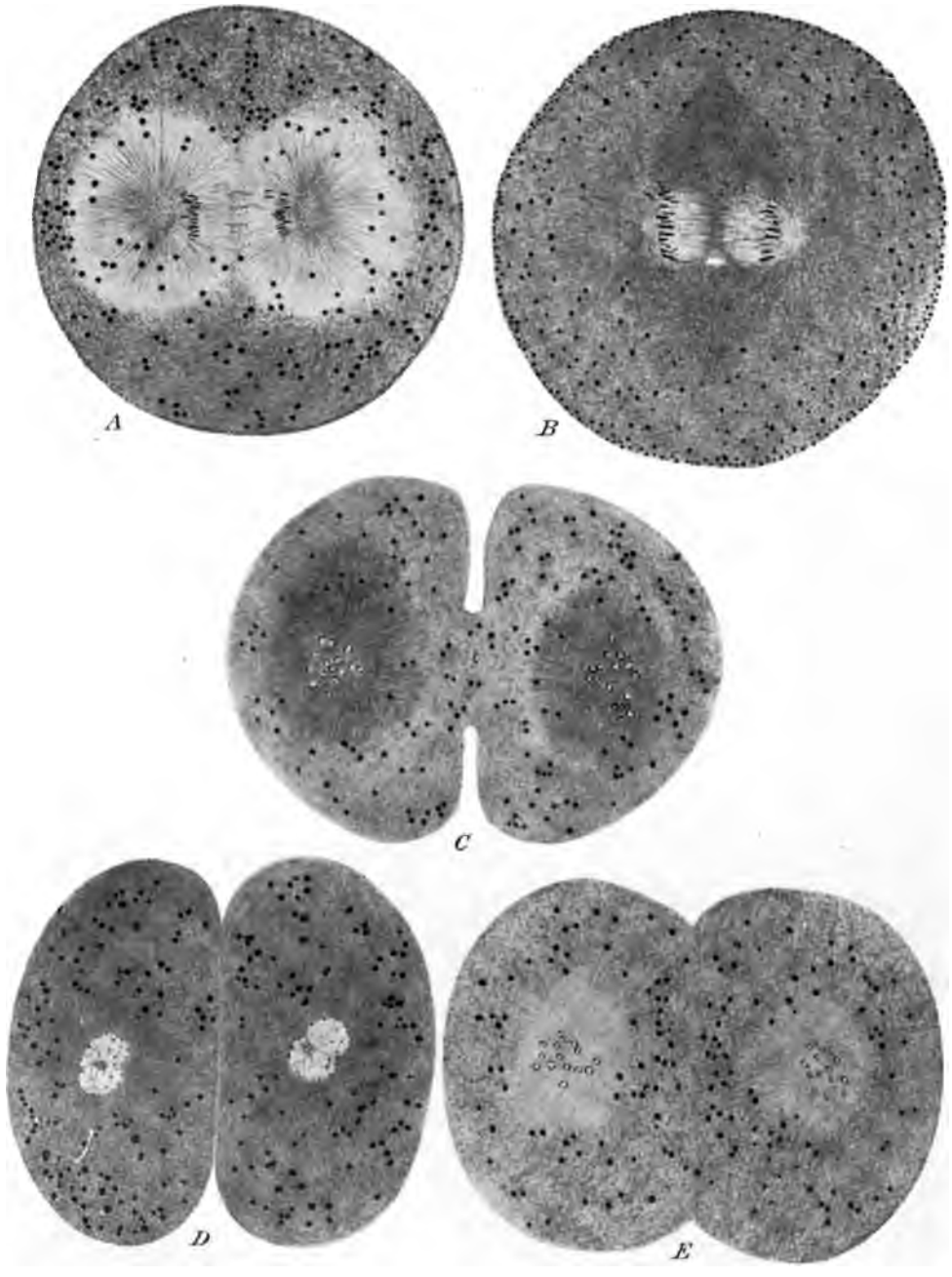
FIG. A, *Cidaris* × *Cidaris*. Anaphase first cleavage.
FIG. B, *Cidaris* × *Cidaris*. Later anaphase first cleavage.
FIG. C, *Cidaris* ♀ × *Tripneustes* ♂. Telophase first cleavage. Zwischenkorper at line of contact between cells.
FIG. D, *Cidaris* ♀ × *Tripneustes* ♂. Late telophase second cleavage.
FIG. E, *Cidaris* ♀ × *Tripneustes* ♂. Earlier telophase first cleavage.

PLATE 2. Magnification and reduction as in plate 1.

FIG. A, *Cidaris* ♀ × *Tripneustes* ♂. Anaphase second cleavage; lagging chromosomes at center.
FIG. B, *Cidaris* ♀ × *Tripneustes* ♂. Second cleavage completed; Zwischenkorper.
FIG. C, *Cidaris* × *Cidaris*. Prophase of mitosis; fat droplets small and have been moved out from region of nucleus.
FIG. D, *Cidaris* × *Cidaris*. Late prophase of mitosis; region of asters freed from fat droplets.
FIG. E, *Cidaris* ♀ × *Lytechinus* ♂. Large fat droplets surrounding nucleus.
FIG. F, *Cidaris* × *Cidaris*. Late telophase; chromosomal vesicles; small fat droplets moving in.
FIG. G, *Cidaris* × *Cidaris*. Chromosomal vesicle; large fat droplets.
FIGS. H to L, *Cidaris* × *Cidaris*. Small area of cytoplasm from one side of the amphiaster during anaphase of mitosis, showing variation in size and relative abundance of droplets.
FIG. H, Clear area surrounding each droplet.
FIG. I, Cytoplasm with a few large droplets.
FIG. J, Cytoplasm with both larger and smaller droplets.
FIG. K, Cytoplasm with numerous small droplets only.
FIG. L, Cytoplasm with numerous large droplets.

PLATE 3. In all of the detailed figures on this plate only the archenteron and a small portion of the posterior end of the gastrula are shown. The relation of the part shown to the entire gastrula may be seen by reference to figure J. All figures except figure J were drawn at a magnification of 1,900 diameters. They have been reduced one-half in reproduction.

FIG. A, *Cidaris* ♀ × *Lytechinus* ♂. Blastula, 18 hours. One cell in blastocœle; cells in wall seem to be in process of withdrawal.
FIG. B, *Cidaris* ♀ × *Lytechinus* ♂. Gastrula, 23 hours. Seven cells in blastocœle.
FIG. C, *Cidaris* ♀ × *Lytechinus* ♂. Gastrula, 24 hours.
FIG. D, *Cidaris* ♀ × *Lytechinus* ♂. Gastrula, 24 hours.
FIG. E, *Cidaris* ♀ × *Lytechinus* ♂. Gastrula, 40 hours.
FIG. F, *Cidaris* × *Cidaris*. Blastula, 18 hours.
FIG. G, *Cidaris* × *Cidaris*. Gastrula, 18 hours.
FIG. H, *Cidaris* × *Cidaris*. Gastrula, 23 hours; 2 mesenchyme cells are in process of withdrawal from wall of archenteron.
FIG. I, *Cidaris* × *Cidaris*. Gastrula, 24 hours; 5 mesenchyme cells in blastocœle at plane of section.
FIG. J, *Cidaris* gastrula, 23 hours; × 180. Camera sketch of living gastrula; 3 mesenchyme cells in the blastocœle.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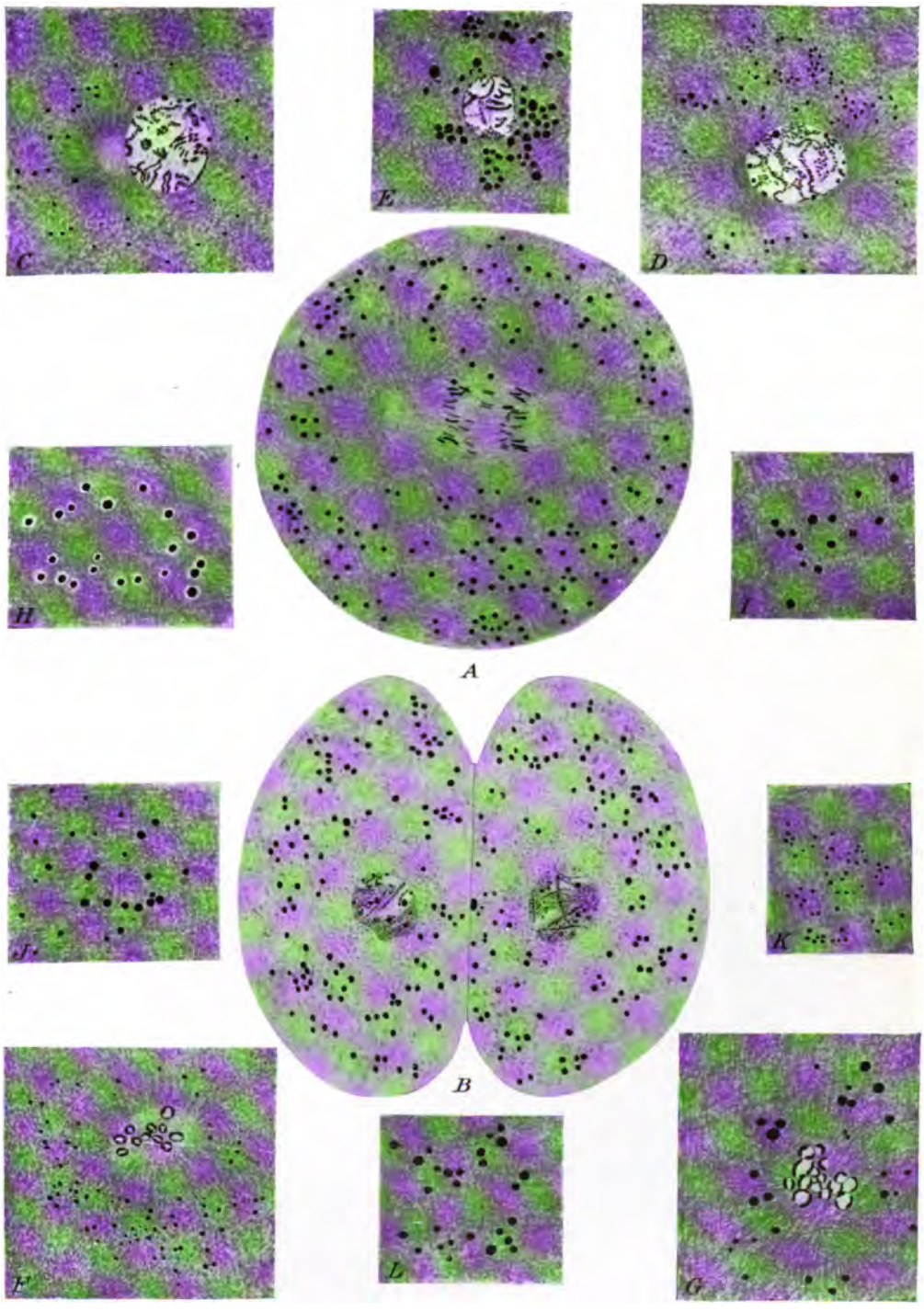
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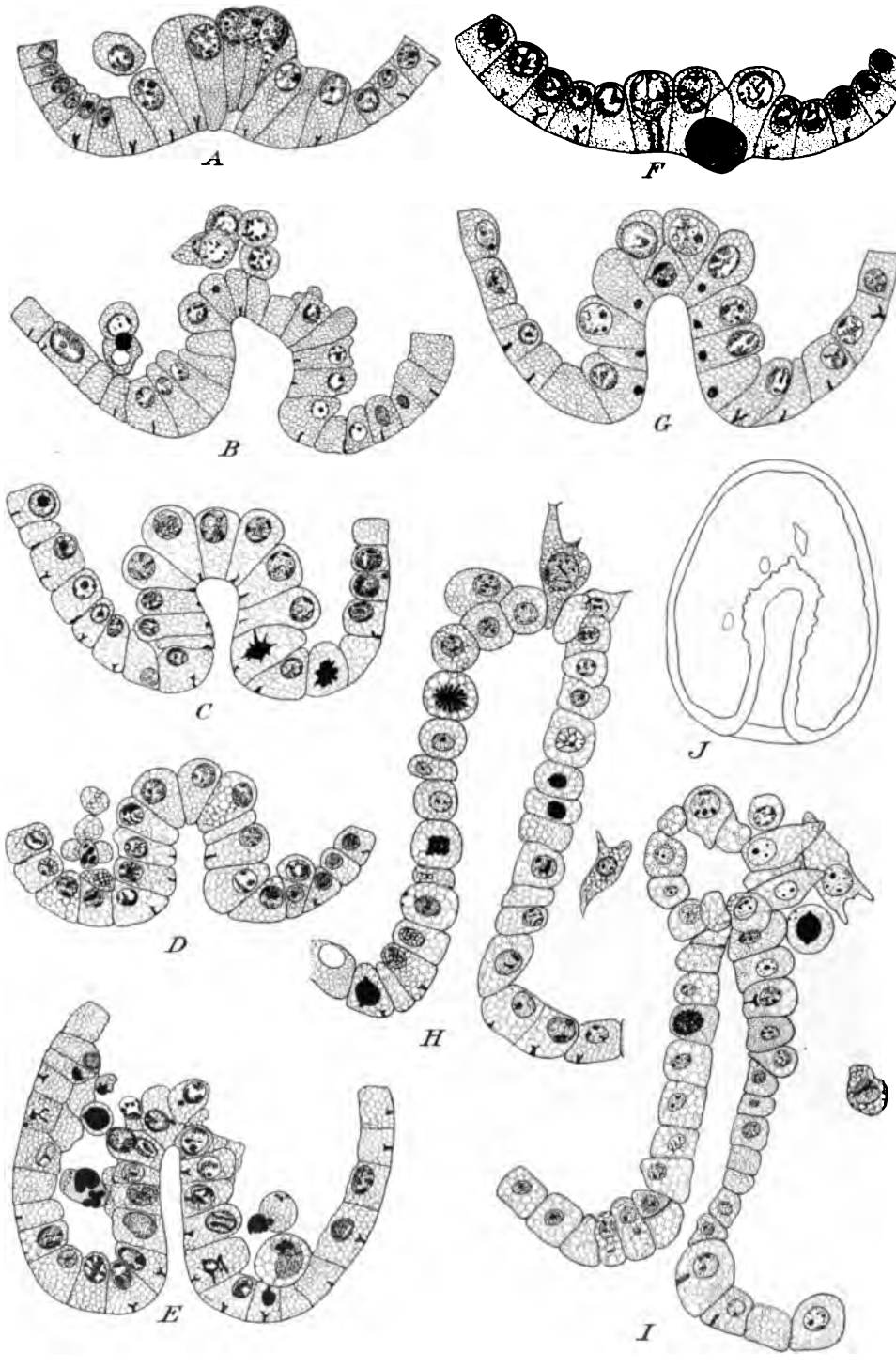
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II.

THE PRODUCTION OF LIGHT BY THE FISHES PHOTOBLEPHARON AND ANOMALOPS.

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THE PRODUCTION OF LIGHT BY THE FISHES PHOTOBLEPHARON AND ANOMALOPS.

By E. Newton Harvey.

GENERAL ACCOUNT OF THE FISHES.

In the Banda Islands, southeast of Amboina, the Moluccas, Dutch East Indies, occur two luminous fish with relatively very large luminous organs. One, *Photoblepharon palpebratus*, called ikan (= fish) leweri (= ?) batu (= stone) by the natives, is known only from this general region, and was first described by Boddaert (1781) from a specimen obtained at Amboina. It is caught with hand-nets in shallow water, swimming singly or few together, among the stones or corals. The other, *Anomalops katoptron*, called ikan leweri ajer (= water) or laut (= sea) by the natives, occurs also, although rarely, at Amboina, Menado (North Celebes), Fiji, New Hebrides, and the Paumotus. It was described by Bleeker in 1858. Unlike *Photoblepharon*, it swims in schools of 100 or more near the surface, in somewhat deeper water. In no other place in the world can these fish be caught so easily or in such numbers as at Banda.

During a trip to this region under the auspices of the Department of Marine Biology of the Carnegie Institution of Washington, in the autumn of 1920, I was able to obtain all the material needed for my investigation without encountering any more difficulty than the general indisposition of the fishermen to work beyond their usual amount, or the advent of rough weather. In dealing with the fishermen, my friend Sech Ahmed bin Said Baadilla acted as interpreter, and it gives me great pleasure to acknowledge his kindness during my stay at Banda Neira. I am also very greatly indebted to Dr. A. L. J. Sunier, director of the Laboratorium voor het Onderzoek der Zee, at Batavia, whose kind hospitality, letters of introduction, and interest in my undertaking made my stay in Netherlands India a pleasure and a success. Through his efforts also I was able to study luminous forms of the Java Sea on the Dutch government's fisheries steamer *Brak*. I take this opportunity of expressing my thanks to the Dutch officials for their courtesy.

These luminous fish of Banda possess more or less commercial value to the fishermen. Both species are caught at night by the natives and used as bait for other larger fish. The luminous organ is cut out and placed on a hook, the light, which is said to last a night, serving as a lure for other fish. From my own experience in the

laboratory the light from both species lasts between 7 and 8½ hours. While the fish occur the year around, they are most easily obtained in October-November and April-May, during the change of monsoon, when the weather is calm. They differ in this respect from the luminous squid (*Watasenia scintillans*) of Japan, which come in toward shore to spawn at only certain seasons of the year and then return to the deeper water. Although the Banda Sea about these islands is very deep (12,000 feet), these luminous fish keep near the surface, living in the relatively shallow water immediately around or between the islands of this volcanic archipelago. They are not so readily caught on moonlight nights, but this is because their light can not be so easily seen by the fishermen and not because they avoid the light of the moon or show any such periodicity in appearance as that of the palolo or other worms.

Nothing is known of the life history of these fish. In October eggs can be squeezed from the females of both species. These are surrounded by jelly, are transparent, and contain large oil droplets, but sink in sea-water. Eggs of *Photoblepharon* are about 1.7 mm. in diameter, and those of *Anomalops* 1 mm. in diameter, without the jelly. *Anomalops* eggs plus sperm did not develop under laboratory conditions, but these were not very favorable. They showed no luminescence on stimulation mechanically, or upon the addition of ammonia to the sea-water containing them.

It is quite natural that the earlier observers, with preserved material at their disposal, should be ignorant of the purpose of the luminous organ. Boddaert thought the function of the organs of *Photoblepharon* was to shield the eyes of the fish from injury by the branches of the coral among which it lived. Lacépède thought it a protection of some sensitive tissue against the rays of the tropical sun. Günther first considered that the structures were light-organs, while Vordermann (1900) actually observed the living fish in 1897 and saw its light. The short paper of Vordermann and the description recorded in the narrative of the *Siboga* expedition by Weber (1902) contained all our knowledge of these fishes until the appearance of an extensive paper by Steche (1909). This excellent monograph deals largely with the histology of the luminous organ and also contains a few physiological observations. Thus, Steche determined that the light shone day and night continuously with an intensity (for one organ of *Photoblepharon*) of 0.0024 meterkertze. Mechanical pressure or chemical stimulation is quite unable to increase the intensity of the light, which can be "turned off" completely or not at all only by mechanical contrivances connected with the organ. Discussion of Steche's histological observations will be given in describing the histology of the organ.

The *Anomalops* obtained by me varied in length from 4 cm. to 11 cm. *Photoblepharon* is about the same size, but the proportions

of the two fish are different, *Photoblepharon* being stouter in proportion to the length. Sometimes the former grows to large size and is caught by hook and line. Mr. Baadilla, of Banda Neira, told me of one about 250 mm. long. The usual size for *Anomalops* is 102 mm. from head to base of tail, 32 mm. high, and 28 mm. thick at the gills. Its luminous organ will measure 12.3 by 5.7 by 1.4 mm. and weigh about 0.08 gram. In *Anomalops* the two luminous organs together make up about 0.58 per cent of the body-weight. This is not as large a proportion as we might expect when we consider that the organ looks very large and is actually one-eighth to one-tenth the length of the fish itself. No doubt the eggs which filled the abdomen of the *Anomalops* examined greatly reduced the weight proportion of luminous organ to whole fish, that would be observed in a fish without eggs.

In both fishes the luminous organ is a compact mass of white to cream-colored tissue, flattened oval in shape, lying in a depression just under the eye and in front of the gills. The organ looks as if made for experimentation, as it is attached only at the dorso-anterior end and can be cut out with the greatest ease, giving a piece of practically pure luminous tissue. The back of the organ is covered with a layer of black pigment which serves to keep the light from shining into the tissues of the fish. In both fish there is a mechanism for obscuring the light, but curiously enough the mechanism developed is totally different in the two species, notwithstanding the fact that in structure the organ is identical in the two and in every detail except proportion the fish are very similar.

In *Anomalops*, the organ is hinged at the antero-dorsal edge and can be turned downward until the light surface comes in contact with a fold of black-pigmented tissue forming a sort of pocket. The light is thus cut off. In *Photoblepharon*, a fold of black tissue has been developed on the ventral edge of the organ socket, which can be drawn up over the light surface like an eyelid, thus extinguishing the light. Why these two fish, so similar in most respects, and especially in the general structure of the luminous organ, should have developed such totally different means of extinguishing the light is a mystery.

As observed by Steche, I find that the organ itself emits light continuously and steadily, in the day as well as at night. No amount of mechanical or electrical (strong interrupted induced shocks) stimulation causes any effect whatever on the intensity. In this respect it differs completely from all other animals and resembles the bacteria and fungi, which also produce a steady light independent of stimulation. One other fish, *Monocentris japonica*, with a paired light-organ at the tip of the lower jaw, behaves as do *Anomalops* and *Photoblepharon*. This peculiarity of steady light, independent of stimulation, should be borne in mind, as it has a very important bearing on the nature of the light of these fishes.

In life, the light of *Anomalops* is constantly being turned on and off, according to Steche, 10 seconds light and 5 seconds dark. *Photoblepharon* in its natural environment shows its light continuously, but in glass jars, either as a result of partial asphyxiation or excitement, its light is also intermittent. The animals appear to be swimming about with bright flash-lights which are turned on periodically. According to the natives, the use of the organ is as a search-light. Its use, according to Steche, is as a "Scheinwerfer" or search-light to attract prey, and the flashing is to mislead its prey.

When brought into the laboratory, in small glass jars, where the supply of air is limited, the fish lose control over the closing mechanism and the flashes become irregular. Just before death from asphyxiation, when the fish swim upside down and slowly, the light is usually not visible, but on actual death, when movement ceases, the organ is exposed and gives forth light, both in *Anomalops* and *Photoblepharon*. This simply means that the muscles involving the closing mechanism pass into the relaxed condition on death. The relaxed condition of these muscles, then, corresponds with the exposed position of the organ.

HISTOLOGY OF THE LIGHT-ORGAN.

Although this paper deals with the chemistry of light-production in *Anomalops* and *Photoblepharon*, an accurate description of the structure of the organ is of considerable interest in view of the rather startling conclusion to which I have come from chemical investigation, namely, that the light-organ is a mass of tissue designed for the nourishment of luminous bacteria, which produce the light. The gross anatomy and histology of the organ is the same in both fishes, with the exception of the movable screen to obscure the light, possessed only by *Photoblepharon*.

Steche describes the organ as an acinose gland made up of a large number of gland-tubes parallel to each other and extending completely across the organ, from the back pigmented surface to front transparent surface, where the light emerges. The ascini have been elongated and arranged parallel to each other. In a parallel section of the fresh organ it is very easy to see these tubes and also the blood-vessels which run between them. A cross-section of the tubes shows that they are pressed into a polygonal shape, separated from one another by sparse connective tissue and arranged in a ring about a blood-vessel, whence they get their oxygen and food-supply. The back ends of these tubes meet a layer of cells containing small granules of guanin, which are believed to act as a reflector layer, in analogy with such a layer found in the luminous organs of other fish. Steche observed that these granules dissolved in formalin and were doubly

refractive, but made no chemical tests for guanin. Back of this reflector layer is a layer of cells containing small black pigment granules which effectively screen the tissues of the animal from its own light. In addition, the socket in which the light-organ lies, the movable screen in *Photoblepharon*, and the whole of the light-organ except the front, almost flat, surface, are covered with this black pigment layer.

Just below the front surface of the organ a number of the tubes unite to form a common reservoir which connects with the exterior by a pore (20 to 30 microns wide) passing through cutis and epidermis. The pores are scattered over the surface of the organ and were overlooked in Steche's first description of the tissue. There is no doubt of these pores, however, as they are very clearly visible in sections of the gland made by Professor Dahlgren, of Princeton University.

At the base, the light-tubes are protoplasmic, but the rest of the tube appears to be one large vacuole of secretion made up in fixed material of small droplets and granules uniformly distributed from base to front of tube. The outlines of the tubes are so difficult to see at the front that Steche gained the impression that the cell itself is directly converted into the secretion. Although no mitoses were observed, the appearance of cells with large nuclei at the base of the tube was such as to suggest a growing layer there which supplies new gland-tube cells to take the place of those wasting away by formation of the light-giving secretion. No luminous material is passed out of the gland, a point which I can confirm from my observations of the living fish, so that Steche believes the light to be burned in the reservoir at the front surface of the gland. The light would therefore be extracellular but intraglandular.

At the front end of the gland-tubes there is a 1- to 2-layered epithelium that passes at the pores into the epithelium of the outer surface of the organ. Here, also, is a tough connective tissue in which are embedded blood-vessels and nerves. The red blood-vessels are very clearly visible in the living organ outlined against the white of the gland. They arise as 9 to 13 vessels passing from both the lower and upper edges of the front surface of the gland and branch to smaller vessels meeting near the middle. A peculiar valve occurs where branch vessels leave the main artery. The blood-supply is exceedingly rich.

Steche could not determine the point of ending for the nerves which follow the blood-vessels, but thinks they pass to the gland-tubes and control the secretion. I should judge it more likely that they are vasomotor in function, but I have no evidence for this point. The nerve is a large branch of the trigeminal-facial complex. There was no indication of a marked center in the brain, such as that possessed by some electric fishes to control their electric organs.

Steche describes the living organ as clear and transparent and bright yellow in color, but becoming cloudy and coagulated in fixing fluids or on death of the fish. I am quite unable to agree with this description. The luminous organ of living fish is white to cream-colored and not transparent. It is fairly firm in consistency, and I have never noted any marked change on death of the fish or removal of the gland from the body of the fish. The fresh gland is firm enough to be cut with a razor into fairly thin sections, in which appear very clearly the parallel gland-tubes with blood-vessels running between them and filled with a row of oval, nucleated red blood-corpuscles. On application of pressure to the cover-glass the gland-tube contents flow downward and mingle with the fluid (sea-water) bathing them, forming a white, milky emulsion. In this emulsion can be seen a great number of small granules and rods, often arranged in spirillum-like rows. The rods are unquestionably bacteria, as they can be seen to move of their own accord, often with a corkscrew-like motion. Some of the granules are probably end views of bacteria, but others may be cell granules of one kind or another. The granules have a weak Brownian movement. The spirilla-like rows may be almost as long as a red blood-corpuscle is wide.

The contents of the luminous cells, then, give an emulsion of bacteria in the sea-water. In the dark this emulsion glows brightly, but whether the light comes from the bacteria or not can not be directly proved. The light is perfectly homogeneous under the microscope, showing no trace of light-giving granules so characteristic of the medusæ and pennatulids. Needless to say, the light of luminous bacteria would also appear homogeneous, as the light of a single bacterium is too weak to be seen through the high power of the microscope and the bacteria are too small to be observed as individuals with the low power of the microscope.

If the material of the gland-tubes is pressed out into *fresh* water a coagulation appears to occur and the material assumes a finely granular net structure in which it is difficult to make out individual particles. Brownian and bacterial movements cease and the emulsion also ceases to luminesce. Bacteriolysis has taken place.

Fresh smears of the luminous gland, kindly stained for me by Professor Dahlgren, show the bacteria very nicely and in great abundance.

While Steche's description of the structure of the light-organ is essentially correct, failure to examine the fresh organ material has led him, I believe, to a misinterpretation of its nature. The bacteria are so numerous and the chemical behavior of the emulsion of the organ (as we shall see) so similar to an emulsion of luminous bacteria that I feel that they are the real source of the light of these fishes. The organ becomes, then, not a gland for the production of a secretion

whose combustion is intraglandular but extracellular, but an organ for the nourishment of symbiotic luminous bacteria. On this view the extraordinary richness of the blood-supply is at once apparent—to supply the oxygen for respiration of the organ cell, for respiration of the bacteria, and for the production of light by the bacteria. Luminous bacteria require an unusually abundant supply of oxygen, as those who are familiar with the growth of them will readily understand.

On this view the existence of pores in an organ which does not produce an external secretion becomes explicable—namely, a means of exit of dead bacteria. It is very likely that other fish may also be found to possess luminous organs for the growth of luminous bacteria. To decide this it will be necessary to study the living animals, as no certain remains of bacteria are to be made out in fixed material. A fish which I suspect may prove to be similar to *Photoblepharon* and *Anomalops* is *Monocentris japonica* of Japan. My suspicion is based on the fact that the light of this fish, two specimens of which I observed at Misaki in 1917, is produced continuously day and night and without change in intensity, just as the Banda fishes.

The view that animal light is due to bacteria is not a new one. It has been advocated by Pierantoni (1918) for some years. He had grown cultures of luminous bacteria from the luminous material of squid and has even gone so far as to suggest that in forms where no bacteria can be demonstrated we are dealing with ultramicroscopic organisms similar to ultramicroscopic pathogenic forms supposed to be present in filterable viruses. While it is certainly not true that the light of all forms is due to luminous bacteria, I think the chemical evidence which follows, together with the ocular evidence already described, is very strongly in favor of the view that the light of these fishes is due to symbiotic luminous bacteria.

LACK OF OXYGEN.

One of the conspicuous anatomical peculiarities of the light-organ is its rich supply of blood-vessels. These can be seen in life, running from the lower (principally) and upper edges of the organ to branch over its surface into capillaries which run between and parallel to the columns of luminous material. The organ is also in a position just anterior to the gills to receive fully oxygenated blood, and in cutting the organ out blood flows freely, showing the presence of large arteries in this region. It is not surprising, then, to find that the organ is very sensitive to lack of oxygen, the light disappearing promptly in its absence. This can be shown for both *Anomalops* and *Photoblepharon* by three methods.

First, it may be readily observed that the light-organs of fish dying in sea-water from lack of oxygen become dimmed. If the fish

are now lifted out of the water to the air, the light immediately becomes bright again. This is not due to stimulation of the fish in handling, because the same amount of stimulation while the organ is under sea-water containing less than the proper amount of oxygen does not increase the intensity of the light. It is interesting to note, in this connection, that strong, interrupted, induced electrical shocks will not cause a luminous organ, dim from insufficiency of oxygen, to glow more brightly. This shows that, for this material at least, the cell is able to absorb all the oxygen *available* and that electrical stimulation can not cause additional oxygen to enter as a result of increased permeability from stimulation.

Second, if a luminous organ is removed from a fish and laid face down on a piece of glass, the light, as observed through the glass, disappears almost instantly, except about the edges of the organ in contact with air. On lifting from the glass the organ glows brightly over its whole surface. The glass keeps the air away and the light then disappears with extraordinary rapidity.

Finally, if one makes an extract of the organ by grinding in sea-water with quartz sand and places the extract in a test-tube, the light quickly disappears, except at the surface of the extract in contact with air. Shaking the tube causes its contents to glow throughout.

In these experiments it is the rapidity with which the oxygen is used up that is astonishing. Similar experiments can be performed with an extract of *Cypridina* or pennatulids, but oxygen is not consumed nearly so rapidly. The situation is exactly as if one had, in sea-water, an emulsion of luminous bacteria, which also use up oxygen with extraordinary activity. The difference between luminous bacteria and extracts of *Cypridina* lies in this, that the bacteria use oxygen not only for light-production but also for respiration. Large amounts of oxygen are necessary for the latter. The extract of these fish behaves like an emulsion of luminous bacteria and furnishes an additional fact in favor of the view that the light is really of symbiotic bacterial origin.

DESICCATION.

If the light-organs of *Anomalops* or *Photoblepharon* are cut out, carefully freed of adherent sea-water, and placed in a desiccator, they dry to a hard, leathery mass which is powdered only with difficulty in a mortar. On adding water, there is no light, or at most a faint light, if the tissue has been dried very rapidly by placing it very near lumps of $CaCl_2$. No doubt a vacuum desiccator would give better results, but certainly there would be no light after drying to compare with the great intensity before drying. In this respect these fish behave as luminous bacteria, which give light on moisten-

ing only if dried very rapidly and if tested with water within a short time after they have been desiccated.

DILUTION.

Despite the fact that there is so little light-material in an organ of these fish which can be dried, there is an amount in the fresh glands which will give a visible light when distributed through an immense amount of sea-water. In one experiment with *Anomalops*, the light-organ was carefully cut out, ground with sand in a mortar, and 10 c. c. sea-water added; 5 c. c. of this brilliant emulsion was then diluted with equal volumes of sea-water successively until the light could no longer be seen. The organ distributed in 1,280 c. c. still gave a good light and in 5,120 c. c. to 10,240 c. c. the light was just visible. The organ measured 12.3 by 5.7 by 1.4 mm. and the organ of the opposite side weighed (fresh) about 0.08 gram. This tissue, therefore, gave light visible in, let us say, about 8 liters of sea-water, or 1 part in 100,000 sea-water.

A strong emulsion of the organ is milky in appearance, due to the small, suspended particles. It resembles a suspension of luminous bacteria in sea-water, and like them the luminous material passes ordinary filter-paper readily. As no porcelain filter was obtainable, I can not say whether the particles will pass one of these or not.

DURATION OF LUMINESCENCE.

A concentrated sea-water extract of the luminous organ of either *Anomalops* or *Photoblepharon* allowed to stand will give only a very faint light after 7 hours and no light after 8½ hours. More dilute extracts in sea-water give light for a shorter time, as do also extracts in more dilute sea-water (1 part fresh water to 2 parts sea-water and 1 part fresh water to 1 part sea-water). These experiments with diluted sea-water were tried in the hope of getting a medium more like the blood of teleosts, which usually have a salt-content considerably lower than sea-water.

If the light of these fishes is of bacterial origin, the bacteria are so dependent on cultural conditions within the living organ that they will not live for more than 7 or 8 hours when removed. The organ of *Anomalops* or *Photoblepharon* kept intact in sea-water or in the dead fish will also give no light if ground in a mortar after a period of 8 hours. These experiments were performed at 29° C. temperature.

Once the light has disappeared from an extract of luminous organs on standing, it can not be regenerated in any way. In this respect the extract of these fish differs from those of pennatulids and jelly-fish, which again give light upon addition of fresh water, and from

Cypridina and fireflies, which again give light on mixing with luciferin. Neither *Anomalops* nor *Photoblepharon* gives the luciferin-luciferase reaction. If fresh water is added to a sea-water extract of the organ of these fish, the light grows rapidly dimmer and disappears. There is no sudden increase in intensity, such as one gets on adding fresh water to extracts of pennatulids and jelly-fish. All these peculiarities are identical with those of an emulsion of luminous bacteria, and again serve to strengthen the evidence that light is due to symbiotic bacterial organisms.

LUCIFERIN AND LUCIFERASE.

In *Cypridina*, *Odontosyllis*, *Pholas*, and fireflies, the presence of luciferin and luciferase can be demonstrated. In *Noctiluca*, pennatulids, jelly-fish, luminous bacteria, and *Chætopterus* it is not possible to demonstrate them; it is also impossible in these fish. Luciferin, if present in the organ, should be prepared by some one of the following methods: (1) Adding boiling water to the excised luminous organs and extracting them in a mortar; (2) heating the concentrated luminous sea-water extract of the organ to (*a*) boiling or (*b*) to a temperature (55° C.) which permanently extinguishes the light.

Luciferase, if present in the organ, should be prepared by some one of the following methods: (1) Extracting with sea-water and allowing the extract to stand for 8 hours till the light disappears; (2) extracting with fresh water; (3) extracting with sea-water and adding such substances as saponin or sodium glycocholate, which causes the light to disappear quickly. Dark solutions which should contain luciferin and luciferase have been obtained by these various methods, but on mixing no light whatever has appeared. The luciferin[1] of these fish also gave no light with *Cypridina* luciferase, nor the luciferase[1] of these fish with *Cypridina* luciferin. In the impossibility of demonstrating a luciferin-luciferase reaction, despite an apparent abundance and persistence of luminous material, *Anomalops* and *Photoblepharon* again agree with luminous bacteria. The luciferin-luciferase experiments may be summed up as follows:

Photoblepharon	luciferase	× Photoblepharon	luciferin	—negative
"	"	× Anomalops	"	— "
"	"	× Cypridina	"	— "
Anomalops	"	× Anomalops	"	— "
"	"	× Photoblepharon	"	— "
"	"	× Cypridina	"	— "
Cypridina	"	× "	"	—brilliant
"	"	× Photoblepharon	"	—negative
"	"	× Anomalops	"	— "

[1] Using these words for solutions which, according to the method of preparation, should have contained luciferin and luciferase.

TEMPERATURE.

The temperature of the water in which these fish normally live varies but little from 27° C. the year around. If a sea-water extract of the luminous organ of *Anomalops* is made and gradually heated in a test-tube, the light dims at 38° and disappears at 41° to 42°. If cooled quickly, the light returns and the heating and cooling can be repeated several times with alternate disappearance and reappearance of luminescence. If heated to about 50° and cooled quickly, there is no return of the light, but there is some recovery on heating to 48° and cooling quickly.

An extract of *Photoblepharon* behaves in just the same way as *Anomalops* on heating under similar conditions, except that the light dims at 40° and disappears at 43° to 44°. Heating to the neighborhood of 51° likewise extinguishes the light permanently.

It should be noted that there is no marked increase in brightness on slight heating, so characteristic of extracts of pennatulids and jellyfish. The sudden brightness in these forms I would interpret to be a heat cytolysis of cells containing luminous material or perhaps a granulolysis of light-producing granules. In the absence of this heat-effect these fish again resemble luminous bacteria. The temperature of extinction is significant, lying as it does in the neighborhood of 40°. This is the general region for extinction of the light of luminous bacteria, whereas *Cypridina*, *Cavernularia*, and several other luminous forms which produce light are affected only by much higher temperatures.

SPECTRUM AND INTENSITY.

Steche reported the intensity of the light of *Photoblepharon* to be 0.0024 meterkertze. This value was arrived at by determining in Banda that he could just read his watch easily by the luminescence of the fish at a distance of 2 meters, after a 5-minute dark adaptation of his eyes. On arrival home, Steche prepared an illuminated slit giving about the same intensity and color as the light of *Photoblepharon*, and found he could read his watch at a distance of 1.75 meters after a 5-minute dark adaptation. The intensity of the slit was therefore 0.75 of that of the luminous organ, and in comparison with a candle the slit was found to be 0.0018 meterkertze. Hence the intensity of one light-organ of a fish was four-thirds of 0.0018 meterkertze or 0.0024 meterkertze. I have made no measurement of the intensity of the light of these fishes, but may remark in passing that it is extraordinarily bright and the living fishes present a remarkable sight as they swim through the water flashing their lanterns—so large in proportion to the body—like great electric torches.

To my eyes the color of the light of both *Anomalops* and *Photoblepharon* is greenish blue. In lamplight it looks green, as does an

emulsion of luminous bacteria. It is greener than *Cypridina*, which looks blue in lamplight and decidedly blue in the dark. Examined with a Zeiss comparison microspectroscope, the spectrum extends, in the case of both fish if lighting brightly, from about $\lambda = 0.45$ to $\lambda = 0.64$ micron. When brightly lighting, the red end is distinctly visible; when somewhat dimmed from lack of oxygen no red can be seen, but only a strip of greenish blue. There are no dark or bright bands, but a continuous spectrum is formed.

CYTOLYSIS.

A luminescent extract of the photogenic gland of *Cypridina* made with sea-water is quite unaffected by the ordinary cytolytic agents. There is neither extinction of light nor increased brightness on mixing with fresh water, on saturation with chloroform, or on addition of small amounts of saponin or sodium glycocholate, or on slight warming. By these means cells are caused to swell and become more or less completely fluid, many of the granules within the cell dissolving at the same time.

A luminous extract of pennatulids (*Cavernularia, Ptylosarcus*) or of jelly-fish (*Æquorea, Mitrocoma*) becomes much brighter on application of cytolytic agents, and then the light disappears completely and can not be resuscitated in any way. Either some photogenic cells in the extract, which are still intact, cytolyze with liberation of photogenic material and production of light, or photogenic granules in the extract dissolve with production of light.

The light of an emulsion of luminous bacteria, on the other hand, is immediately extinguished by the above-mentioned cytolytic means, without any preliminary increase in brightness. Light-production is dependent upon an intact bacterial cell, and when bacteriolysis has occurred the photogenic power is lost completely.

Both *Anomalops* and *Photoblepharon* extracts behave toward cytolytic agents as an emulsion of luminous bacteria. The light disappears on addition of three volumes of fresh water, but not on addition of three volumes of isotonic salt or cane-sugar solution. A drop of chloroform added to a test-tube of luminous emulsion puts out the light immediately, as does also a pinch of saponin or of sodium glycocholate, the latter more readily than the former. There is no initial increase in brightness in the case either of the bacteria or of these fish.

Like an emulsion of luminous bacteria, the light disappears from an extract of *Anomalops* photogenic organ, if crystals of cane sugar, $MgSO_4$, or $(NH_4)_2SO_4$ are added, but returns if the mixture is immediately diluted with sea-water, most readily and bright in the case of the cane sugar. Addition of alcohol also causes a reversible extinction. As this behavior toward sugar and salts is similar to that

of luminous extracts in general, as well as suspension of luminous bacteria, it throws no light on the bacterial nature of the luminescence of these fish. The effect of cytolytic agents, however, does indicate a bacterial origin of the light.

SODIUM FLUORIDE.

Sodium fluoride is often used to determine if a process depends on the integrity of the cell, on some vital peculiarity, or is of enzyme nature. Sodium fluoride in 1 per cent concentration is said not to affect the activity of enzymes. It is certainly true that 1 per cent NaF does not affect the luminescence of *Cypridium* extract (Harvey) or of *Pholas* extract (Dubois). Sodium fluoride in 1 or 1.5 per cent concentration does, however, extinguish rapidly the light of an extract of *Anomalops* made with 3 per cent NaCl (to prevent precipitation of the NaF by the Mg and Ca of sea-water).

POTASSIUM CYANIDE.

Although potassium cyanide affects many kinds of oxidations, it has very little effect on the luminescence of extracts of luminous animals. This is true for *Cypridina*, *Cavernularia*, fireflies, and *Noctiluca*. Very small amounts will kill animals and even 0.00025 per cent KCN is sufficient to cause asphyxiation and death of fresh-water fishes in 24 hours.

TABLE 1.—*Effect of KCN on Luminous Bacteria.*

Concentration of KCN.		Light after—			Light disappears in—
Gram mols. per liter.	Per cent.	10 min.	60 min.	24 hrs.	
M/10	0.65	.....	.....	.....	3 min.
M/20	.325	.....	.....	.....	4 min.
M/40	.162	.....	.....	.....	6 min.
M/80	.081	Faint.	Very faint.	.....	80 min., about.
M/160	.04	Faint.	Very faint.	.....	
M/320	.02	Slightly dim.	Slightly dim.	.....	
M/640	.01	Good.	Good.	.....	
M/1280	.005	Good.	Good.	.....	
M/2560	.0025	Good.	Good.	Good.	
Sea-water.		Good.	Good.	Good.	

It was found that KCN extinguishes the light of these fish more readily than that of *Cypridina* or *Cavernularia* and about as readily as that of luminous bacteria. A comparison can be made from two tables which I append, although the times observed and concentrations used are not exactly the same in the two cases. One gives the effect on a strain of luminous bacteria which I studied in 1915, but have not previously published the results. The second gives the

action of KCN on an emulsion of the luminous organ of *Photoblepharon*. The KCN was dissolved in sea-water, and this solution was diluted with an equal volume of sea-water each time. The concentration of KCN necessary to inhibit luminescence of these fish is sufficiently close to that inhibiting the luminescence of bacteria to supply one more fact in favor of the view that the light of *Photoblepharon* and *Anomalops* is of bacterial origin.

TABLE 2.—*Effect of KCN on Emulsion of Photoblepharon Luminous Organ.*

Concentration of KCN.	Light after—			Light disappears in—
	1 min.	10 min.	60 min.	
0.5 p. ct.	Dim.	.....	.....	About 8 min.
.25	Dim.	Very faint.	.....	About 20 min.
.125	Fair.	Faint.	.....	About 30 min.
.062	Good.	Fair.	.....	About 40 min.
.031	Good.	Fair.	.....	
.015	Good.	Fair.	Very faint.	
.008	Good.	Good.	Very faint.	
.004	Good.	Good.	Very faint.	
.002	Good.	Good.	Fair.	
Sea-water.	Good.	Good.	Good.	

CULTURE EXPERIMENTS.

Despite the parallel in behavior of an extract of the luminous organ of these fish and an emulsion of luminous bacteria, final proof of the bacterial nature of the light must come with the artificial cultivation of the organisms. Although not equipped for bacteriological work in Banda, I have endeavored to obtain luminous cultures by growth of bits of the luminous gland on various media. Growth of some kind of organism has been abundant, but no light has appeared in any case. It is possible that this growth was actually made by the luminous organism, but that no light was produced under artificial conditions. Giard and Billet have described a malady of sand-fleas, an infection of the animals with luminous bacteria, which eventually led to their death. They were able to inoculate uninfected sand-fleas, which would then become luminous, with the organisms, and grow them on artificial media, but light never appeared under these artificial conditions. However, the cultures inoculated into living sand-fleas would luminesce in the animal. Apparently some special nutrient material is necessary for luminescence in this particular organism, and it is not improbable that a luminous bacterium which has developed into a symbiotic organism, such as we may suppose to be present in these fish, would require special nutrient substances. The ordinary luminous bacteria of the sea can be grown and luminesce with great regularity on almost any medium. Tar-

chanoff has inoculated them in frogs and produced luminous animals. However, non-luminous strains of luminous bacteria have been described by Beijerinck. There is a possibility, then, that the growth I observed on my culture media was the form which produced light under special conditions of the luminous organ of the fish. On the other hand, although the transfer was made with sterile instruments from the interior of the organ, there is always the possibility of contamination, and nothing certain can be stated regarding the nature of the cultures obtained.

The culture media used were the following:

1. Sterile muscle of *Anomalops* in sea-water.
2. Unsterile muscle of *Anomalops* in sea-water.
3. Sterile muscle of *Photoblepharon* in sea-water.
4. Unsterile muscle of *Photoblepharon* in sea-water.
5. Potato slab (sterilized) in sea-water.

6–12. Agar-peptone-amino-acid-sea-water of a reaction varying from colorless to decidedly pink to phenolphthalein.

The culture medium for 6 to 12 was made by digesting the white of one boiled egg for 24 hours with trypsin solution in 50 c. c. water, diluting to 425 c. c. with sea-water, adding 1.5 per cent agar-agar, and sterilizing. The material was then tubed and NaOH added in successively increasing amounts to each tube to give a range of acidity on each side of neutrality. These tubes all produced a good growth of bacteria, except the deep-pink decidedly alkaline ones; 5 produced no (?) growth; 1 to 4 abundant growth of bacteria. The best growth occurred on the light-pink medium. No light appeared in any tube. Further work is therefore necessary to settle this interesting and important question of the artificial cultivation of bacteria from the luminous organs of *Anomalops* and *Photoblepharon*.

SUMMARY.

The light of the luminous fishes *Photoblepharon* and *Anomalops* appears to be due to luminous bacteria living in the luminous organ. Previously the organ had been considered a gland, producing a luminous secretion oxidized within the gland. Despite the general appearance of an organ of secretion, no luminous material is excreted to the sea-water by the living fish. If the organ is teased in sea-water and examined under the microscope, innumerable motile rod-shaped bacteria, sometimes forming spirilla-like chains, can be seen. Stained smears of the organ show the bacteria nicely.

In chemical respects an emulsion of the organ behaves just as an emulsion of luminous bacteria and differs in one way or another from extracts of other luminous animals. These various characteristics are as follows:

1. The light-organ is extraordinarily well supplied with blood-vessels and the emulsion is fully as sensitive to lack of oxygen as are luminous bacteria. Light ceases very quickly in absence of oxygen.

2. If dried, the organ will give only a faint light when again moistened with water. This is characteristic of luminous bacteria. The luminous organs of most other forms can be dried without much loss of photogenic power.

3. Luciferin and luciferase can not be demonstrated; this is also true of luminous bacteria.

4. The light is extinguished without a preliminary flash by fresh water and other cytolytic (bacteriolytic) agents. The significance of this is discussed in the text.

5. Sodium fluoride of 1 to 0.5 per cent concentration extinguishes readily the light of an emulsion of the gland.

6. Potassium cyanide has an inhibiting effect on light production in about the same concentration as with luminous bacteria.

To these observations must be added the very suggestive fact that the light of *Photoblepharon* and *Anomalops* continues night and day without ceasing and quite independently of stimulation. This is a characteristic of luminous bacteria and fungi alone among organisms, and very strongly suggests that the light is actually due to symbiotic luminous bacteria.

Actual proof that the bacteria found in the organ are luminous can come only when these are grown artificially. My attempts in this direction have failed. Good growths of bacteria were obtained on pepton-agar, but they produced no light. One might expect that a symbiotic form would require rather definite food materials to produce light, and it is, perhaps, not surprising that culture experiments have failed. Certainly, the ocular and chemical evidence, if not the cultural evidence, supports the view that the light of these living fish is bacterial in origin.

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III.

HYDROGEN-ION CONCENTRATION AND ELECTRICAL CONDUCTIVITY OF THE SURFACE WATER OF THE ATLANTIC AND PACIFIC.

By ALFRED GOLDSBOROUGH MAYOR.

Three charts.

HYDROGEN-ION CONCENTRATION AND ELECTRICAL CONDUCTIVITY OF THE SURFACE WATER OF THE ATLANTIC AND PACIFIC.

By Alfred Goldsborough Mayor.

The hydrogen-ion concentration of sea-water was determined by placing 0.4 c. c. of 0.1 per cent of the red dye thymolsulphonephthalein in 70 per cent alcohol, in a test-tube of resistance glass, 24 mm. in caliber, then adding sea-water so as to make up 30 c. c. of solution. The more alkaline the sea-water the more blue the solution, while a yellow color appears more and more pronounced in less and less alkaline sea-waters. Thus comparing the color of the solution in the test-tube with a graded series of sealed tubes whose colors correspond with known hydrogen-ion concentrations of sea-water, we can readily determine the hydrogen-ion concentration of our sample. A series of such tubes, ranging from 7.95 to 8.3 PH, was standardized by Professor J. F. McClendon and kindly presented to the author in 1917, and I have since then restandardized these tubes at intervals of two years by comparison with determinations of PH made by a Leeds and Northrup potentiometer, but the color of the tubes has not changed appreciably in the interval. When not in use the tubes are, however, kept in the dark to avoid the possibility of light changing their color.

The method for making up the solutions in these standard colorimetric tubes is described by McClendon, Gault, and Mulholland in publication No. 251, page 44, Carnegie Institution of Washington, 1917.

As is well known, Kohlrausch found that in the purest distilled water the molecules are only slightly dissociated, so that there is only about 1 gram of hydrogen ions in 10,000,000 liters of water; or the hydrogen-ion concentration is about 10^7. These hydrogen cations are of course balanced by 10^7 concentration of OH anions in the water. In sea-water, however, the hydrogen-ion concentration is about 10^8, and the OH-ion concentration 10^6.

In order to avoid writing negative exponents, Sörensen (1909, p. 28) devised the symbol "PH" to indicate the negative logarithm of the hydrogen-ion concentration. Thus 10^{-8} would be PH 8 in Sörensen's system, and a hydrogen-ion concentration of $\frac{1}{2.5 \times 10^8}$ $= 0.4 \times 10^{-8}$ would be written PH 8.398, because 0.398 is the logarithm of 2.5 and 8.0 is the logarithm of 10^8; hence $8.0 + 0.398 =$

8.398. It is, however, difficult to think in terms of negative logarithms, and so the tables at the end of this paper give the PH and also the hydrogen-ion concentration of the sea-water expressed arithmetically. Despite its artificiality, however, one soon finds that the PH system gives a clearer idea of the alkalinity or acidity of a solution than does a direct expression of the hydrogen-ion concentration. Thus, in testing water, PH 7 would indicate practical neutrality; PH above 7, alkalinity; and below 7, acidity.

The carbon-dioxide tension of the sea-water was calculated from the PH and the temperature by the method devised by McClendon, Gault, and Mulholland (1917, Carnegie Inst. Wash. Pub. No. 251, p. 36). McClendon found that the PH of sea-water falls 0.01 for 1° C. decline in temperature. Thus if the PH be 8.25 at 27° C., it may be expected to be 8.24 at 26° C. While this is true under normal conditions, if the sea-water be diluted with river-water, or if there be upwelling of cold currents carrying water rich in CO_2 to the surface, the PH may *rise* while the temperature declines. Thus, near the equator in the Pacific, I have observed a rise of 0.13 in the PH while the temperature sank 0.45° C., due to the upwelling of water from the depths.

The salinity of the sea is expressed in grams of total salts per 1,000 grams of sea-water, and was determined by the well-known method of using a standard $AgNO_3$ solution with K_2CrO_4 as an indicator, and testing against a sample of standard sea-water obtained from Professor Martin Knudsen.

The thermometers used read to 0.1° C. and were compared with a thermometer which had been standardized by the U. S. Bureau of Standards.

Tests made on the yacht *Anton Dohrn* in Florida showed that one might take samples of sea-water from the stern of the vessel while in motion without any detectable error in the PH, the result being the same as if one dipped the sample up from the bow or stopped the ship and went out in a small boat for it.

Of course the only certain way for determining a current while at sea is to anchor and use current meters, but in default of this possibility we were obliged to rely upon the difference between the position the ship *expected* to make and what she did make—the difference being ascribed to "currents." This is, of course, a crude and inaccurate method, for it makes no allowance for leeway due to wind or for errors in steering, but it was the only method available.

The thymolsulphonephthalein colorimetric tubes gave correct readings when used for testing the PH of sea-water of salinity 0.32 or 0.33 per cent, but for higher salinities a correction of −0.01 is to be applied to the PH as read on the tube for every unit in rise of salinity. Thus, for salinity 34, if the tubes read 8.22 the correct

reading would be 8.21; and for salinity 30, if the tubes read 8.22 the true PH would be 8.24. These corrections are, however, of minor significance for Pacific sea-water, for one can not read the PH on the colorimetric tubes to within 0.02 PH, although one can detect a difference of 0.03 PH.

Upon being taken from the sea, the water was at once tested for temperature and PH, and a sample was preserved in a rubber-stoppered bottle for determination of salinity; this was done as soon as possible after the end of the voyage. Some of the samples were tested by Professor L. R. Cary for oxygen, using Winkler's method, and in all such cases the water was tested immediately upon being taken from the ocean.

OBSERVATIONS.

In connection with these tests of hydrogen-ion concentration, the electrical conductivity of the sea-water off Tutuila, Samoa, and at Tortugas, Florida, was determined by Kohlrausch's method, using a Wheatstone bridge designed by Leeds and Northrup for this special purpose, and having a tunable telephone for a detector. As will be seen in table 1, the sea-water of Tortugas has a higher coefficient of electrical conductivity than that of Samoa, due to the higher salinity of Atlantic water. The table gives the data of electrical conductivity of Samoan sea-water at various temperatures, that of N/10 KCl being unity at the corresponding temperature. This sea-water was collected one-fourth mile east of Cape Matutula, the easternmost point of Tutuila, on April 28, 1917. The salinity was 34.83, corresponding to a chlorine content of 19.28 grams of chlorine in 1,000 grams of water. The hydrogen-ion concentration was 0.563×10^{-8} (PH 8.25) at 28.2° C. The second column shows the electrical conductivity of sea-water, that of N/10 potassium chloride at corresponding temperature being unity.

TABLE 1.

Temp.	Elec. cond.
°*C.*	
23	3.8996
24	3.8980
25	3.8958
26	3.8934
27	3.8903
28	3.8871
29	3.8838
30	3.8807

At Tortugas, Florida, the conductivity of sea-water having 20.06 grams of chlorine in 1,000 grams of water, corresponding to a salinity of 36.24, was determined by the same apparatus, and with a portion of the same KCl solution used in Samoa. It was found that the conductivity of this Tortugas sea-water at 25° C. was 4.163, and at 30° C. it was 4.117 times as great as that of N/10 KCl solution at the same temperature.

The average of 62 observations gives 34.87 as the salinity of the surface-water between the Hawaiian Islands and Samoa, whereas in the American tropical Atlantic the salinity is above 36.

As McClendon states, temperature is the most important factor determining the PH of the surface water of the sea; for, as the temper-

ature rises, the carbon dioxide is driven out of the water and the alkalinity increases; whereas, if the temperature falls, the water attains an increased capacity for absorbing CO_2 from the atmosphere or of retaining CO_2 derived from animals or plants, and the H-ion increases in the water. Thus, in our observations of PH off theAtlantic coast of North America, the cold water off Yarmouth, Nova Scotia, which was 1.4° C., had 7.96 PH on March 26, while the tropical water of the Sargasso Sea had 8.25 PH at 23.55° C. on March 10, 1918.

In lagoons such as that of Tortugas, Florida, and inclosed shallow areas, McClendon found there was a diurnal variation in the PH, the water becoming more alkaline by day and relatively acid during the night. This he correctly attributed to the effect of photosynthesis by plant life, which is active in daylight but ceases during the night. Over the deep sea this effect is apparently neutralized by the stirring of the water due to waves, and perhaps by a moderate amount of interchange between the surface water and the deeper layers. Over shallow regions, where the water may become impounded in tide-pools at low tide, the effect of photosynthesis is often very marked, the PH changing greatly while the temperature may change but little. Thus, over the Aua reef-flat at Pago Pago Harbor, Samoa, where the water was impounded and stagnant at low tide of the spring tide of July 16, 1920, the conditions as compared with those of the ocean-water just seaward of the outer edge of the reef-flat were as shown in table 2.

TABLE 2.

Date.	Locality.	Depth.	Temp.	PH of water.	Salinity in grams of total salts per 1,000 grams of water.	Oxygen per liter of water by Winkler's test.
1920			° *C.*			*c. c.*
July 16, 1^h41^m p.m.	400 ft. from shore, impounded water of reef-flat.	5.5 in.	27.4	8.6	34.79	8.44
July 16, 1^h30^m p.m.	Open sea, just off reef-flat.	5 fath.	26.75	8.25	34.7	4.67

At 27° C. the sea-water would be saturated with oxygen if it contained 6 c. c. of oxygen per liter of water, but we see that the ocean-water outside the reef contained only 4.67 c. c. of oxygen and was therefore below saturation, while the shallow water of the reef-flat which had been impounded in sunshine for about 2 hours at low tide had 8.44 c. c. of oxygen per liter, thus having gained 3.77 c. c. of this gas per liter in this short time, and becoming supersaturated by about 2.4 c. c. of oxygen per liter. The rise in PH from 8.25 to 8.6 was of course due to the loss of CO_2 resulting from the photosynthesis of

the numerous algæ growing over the floor of the reef-flat. In fact, the CO_2 tension in this impounded water was reduced to 0.8 ten-thousandth of an atmosphere, whereas in the sea-water outside the reef-flat it was 2.7 ten-thousandths.

The PH of sea-water is also lowered by fresh water pouring out from rivers or brackish bays, and one observes this effect as one passes the entrance to Delaware Bay, the Chesapeake, New York Harbor, or Long Island Sound. The water from these bays, and especially from New York Harbor, is more or less charged with decomposing animal matter derived from sewage which drifts southward along the coast. Such water is low in salinity and laden with carbon dioxide, which lowers its PH. Thus, off Barnegat, New Jersey, at 10^h 15^m a. m. on June 25, 1919, the water showed 8.06 PH at 19.5° C., and its calculated CO_2 tension was 4.2 ten-thousandths of an atmosphere; so it must have been discharging CO_2 into the air. Similarly, off Golden Gate, San Francisco Harbor, the water on May 1, 1917, was 7.85 PH at 10.5° C., and its CO_2 tension was apparently 5.4 ten-thousandths of an atmosphere. In both these cases the water was discolored and evidently contained decomposing land waste. Dr. R. P. Cowles tells me that he found the PH of the bottom water of Chesapeake Bay to range from about 7.75 to about 7.28.

The dull-gray-green water that creeps down the coast of the United States from the Gulf of St. Lawrence southward is about 8.0 to 8.1 PH, while the deep-blue water of the Gulf Stream is 8.2 to 8.24. The dull color of this shore water may to some degree be due to pelagic plant life, but it is discolored in greater measure by the drainage and waste from the thickly inhabited shore. One could readily ascertain when the ship passed out of the Gulf Stream into the shore current or vice versa by simply observing the sudden change in the PH from about 8.22 to 8.1 or less when one entered the shore current; but this method is not likely to be of use in navigation, for the change in the color of the water itself is equally good as an indication, and, moreover, the soundings on this gradually shelving shore are so characteristic and reliable that they alone afford good information respecting the position of the ship.

Along the Pacific coast of the United States the upwelling of deep water which has been demonstrated by McEwen (1910, 1918, etc.) lowers the temperature and brings water rich in CO_2 to the surface, thus lowering the PH, but this water with a low PH of about 8.0 may extend for 300 miles or more offshore; so in this region we could not be certain of the close proximity of the coast merely by observing a lowering of the PH of the water.

The most remarkable upwelling of cold, deep water to the surface is encountered in the mid-Pacific, at or near the heat equator, which ranges from near the geographical equator to about 5° N. latitude,

dependent upon the season. This fact has been known since the voyage of the *Challenger* in 1873 (Narrative of the *Challenger* Expedition, vol. 1, part 2, p. 758, chart No. 19). I have crossed the equator in about longitude 165° W. eight times since 1917, and at or near the equator we usually entered a region wherein the surface water was of lower temperature than to the northward or southward of this place (table 3).

TABLE 3.

Date and time.	Latitude.	Temp. of surface water of sea.	Direction toward which surface current was flowing.
		° *C.*	
Mar. 1, 1917, noon.....	6°35′ N.	26.1	E. strong.
Mar. 2, 1917, noon.....	1 07 N.	24.2	NW.
Mar. 3, 1917, noon.....	4 34 S.	26.4	No current.
Apr. 20, 1917, noon.....	5 10 S.	26.75	Easterly.
Apr. 21, 1917, noon.....	Equator.	24.95	E. strong.
Apr. 22, 1917, noon.....	5°42′ N.	25.9	No current.
June 28, 1918, noon.....	1 17 N.	28.5	Easterly.
June 28, 1918, 5^h30^m p.m.	Equator.	27.7	Easterly
June 29, 1918, noon.....	4°23′ S.	28.3	Easterly.
Sept. 8, 1918, noon.....	1 25 S.	28.9	Westerly slight.
Sept. 8, 1918, 4^h54^m p.m..	Equator.	29.1	Westerly slight.
Sept. 9, 1918, noon.....	4°36′ N.	29.5	Westerly slight.
July 17, 1919, noon.....	6 35 N.	28.3	No current.
July 18, 1919, noon.....	1 18 N.	28.6	No current.
July 19, 1919, noon.....	4 06 S.	28.8	No current.
Sept. 18, 1919, noon.....	4 57 S.	28.8	No current.
Sept. 19, 1919, noon.....	0 31 N.	28.6	W. slight.
Sept. 20, 1919, noon.....	6 05 N.	29.4	W. slight.*
Mar. 29, 1920, noon.....	7 09 N.	27.2	Westerly.
Mar. 30, 1920, noon.....	1 31 N.	26.9	Westerly.
Mar. 31, 1920, noon.....	4 32 S.	29.1	Southerly.
July 30, 1920, noon.....	4 08 S.	28.4	No current.
July 31, 1920, noon.....	1 18 N.	27.5	No current.
Aug. 1, 1920, noon.....	6 44 N.	28.5	Strong easterly.

* At 5 p. m. September 20 current was strong easterly until 9 p. m.

It will be seen that on six of these eight voyages we crossed a region of low temperature near the equator, with warmer water both to the north and to the south of it. Moreover, on five of the eight voyages we encountered a surface current setting toward the east in this region, and thus contrary to the prevailing westerly drift of the surface water over the tropical belt of the Pacific. Now, it is well known that a surface current moving toward the *west* will set up a current toward the *east* in the deeper waters. This subject has been admirably treated by W. J. Sandström in his Hydrodynamics of Canadian

Atlantic Waters, Canadian Fisheries Expedition, under the Direction of Dr. Johan Hjort, 1914–1915. Sandström applies the Bjerknes theory of circulation to the waters of the Newfoundland region, which shows that Archimedean forces have more to do with the formation of ocean currents than has the wind. Thus, the Gulf Stream flows from the tropics toward Spitzbergen because the light surface layer of the ocean, which is heated by the sun, is 600 meters deep in the tropics and only 200 meters deep at Spitzbergen; hence the thicker, deeper part of this wedge of light water must constantly flow toward its thin edge at Spitzbergen in a futile attempt to overcome this difference in thickness and reduce the whole wedge to a horizontal surface layer of uniform thickness. Of course, if this were ever accomplished, the current would stop after a few oscillations, but the unequal heating ability of the sun in the tropics and in the Arctic regions keeps the current moving.

We can not dwell upon this interesting subject, nor is it necessary so to do, for it could hardly be more clearly and simply explained than by Dr. Sandström. Suffice it to say that the prevailing westerly drift of the hot, light surface waters in the tropics must produce an easterly current in a heavier and colder layer of water which lies beneath the surface. At or near the heat equator, however, we would expect that this deep layer would at times be brought to the surface by the upwelling known to exist in this region. This would, however, not interfere with its horizontal movement until it reached the surface and moved against the prevailing wind. As is well known, the rotation of the earth about its axis gives to ocean currents in the northern hemisphere a tendency to swerve toward the right. On the equator, however, there is no such tendency, but it increases as the sine of the latitude, although in a latitude so low as 5° N. it would be practically negligible. Hence, in this region, if the surface current moves toward the west the deep layer would move toward the east, and there would be but little tendency for it to diverge toward the southeast and south. This tendency to swerve toward the right is of course not wholly lacking even in low latitudes in the northern hemisphere, and thus the great westerly drift of the surface water of the tropical Pacific eventually turns northwestward and finally northward, and flows along the coasts of China and Japan as the "Japan Current."

If the easterly surface current which is sometimes met with in about 5° north latitude in the mid-Pacific consists of deep water which has been brought to the surface by upwelling, it might, for a time at least, retain some of the characteristics of the deep water of the ocean, even after it reaches the surface.

Thus we may readily account for the slightly lower temperature of the water of these easterly currents as compared with that of the

westerly surface drift to the northward or to the southward. Moreover, the PH of this easterly-moving water ought generally to be lower than that of the westerly drift, for the cold waters of the depths are richer in CO_2 than is the warm surface layer. Our observations indicate that this is probably the case; the results upon the eight voyages across the region in the mid-Pacific from 6° N. to 2° S. are shown in table 4.

TABLE 4.

Direction of surface current.	Observed range in PH of surface water.	Average PH for all observations.
Westerly	8.17 to 8.25	8.21
No current	8.08 to 8.22	8.19
Easterly	8.1 to 8.23	8.18

A low PH when the current is easterly is, however, not always observed. Thus, on August 1, 1920, the ship ran out of the prevailing westerly drift at about 8 a. m. and was in a strong easterly current until about 4 a. m. August 2, and yet the PH of this easterly current was exactly the same as that of the westerly drift to the north or the south of it. Naturally, if deep water rich in CO_2 comes to the surface, it soon becomes warmed, and thus its excess of carbon dioxide is discharged into the air until the CO_2 tension of the water is about in balance with that of the air; and after this process is completed it might, due to momentum, still retain some of its easterly movement, but its PH would be the same as that of the prevailing westerly surface drift. It seems probable, therefore, that in cases where we find an easterly drift in the mid-Pacific in about 5° N. latitude, and its PH is about 8.23, it has been for so long a time on the surface that it has attained the temperature and PH characteristic of the westerly surface drift.

If these easterly drifts be derived from deep water which has upwelled to the surface, their average CO_2 tension ought to be higher than when the current is moving in a westerly direction, and averaging the calculated CO_2 tensions of the water between about 6° N. latitude and 2° S. latitude, observed on our eight voyages across this region in the mid-Pacific, we find that this seems to be the case, as appears in table 5.

It seems, then, that the CO_2 tension of the surface water in these easterly counter currents is appreciably higher than in that of the prevailing westerly surface drift. The atmospheric CO_2 has a tension of about 0.0003 of an atmosphere, and thus it appears that these easterly currents probably discharge CO_2 into the air. In this connection it may be of interest to observe that L. R. Cary (1917) found that the oxygen content of these easterly currents was higher than that of the westerly drift.

Thus the facts seem to warrant the inference that easterly counter currents, such as are found in about 5° N. latitude in the mid-Pacific and possibly also the Guinea Stream of the tropical Atlantic, are composed of water which has upwelled to the surface.

Henderson and Cohn (1916, p. 621) conclude from laboratory experiments that upon the whole, in most places and at most seasons, carbon dioxide must be escaping from the sea into the air, although they also state that the balance is doubtless restored by CO_2 entering the water from the air in the polar regions. These authors did not consider the effect of photosynthesis by marine plants, which McClendon afterward showed to be such an important factor. Were it not for photosynthesis, it is probable that large quantities of carbon dioxide would escape from the sea in the tropics, but, instead of this, McClendon, Wells, and I find that the warm waters are nearly in balance with the atmosphere.

TABLE 5.

Direction toward which surface current was moving.	Range in CO_2 tension of water in terms of 0.0001 atmosphere.	Average CO_2 tension in terms of 0.0001 atmosphere.
Easterly	3 to 4	3.5
No current	3 to 4.4	3.3
Westerly	2.7 to 3.2	3.1

My observations along the Atlantic coast between Nova Scotia and Florida, from December to March, show also that the coastal current during these cold months has a CO_2 tension somewhat below that of the atmosphere, and this may be due to the great concentration of plant life in these cold waters.

Thus, according to my observations, the averages for the shore current, the salinity of which ranges from 30 to 33, between Nova Scotia and northern Florida in winter, are: Temperature 6.7° C., salinity 31.7, P_H 8.05, and CO_2 tension 2.5 ten-thousandths of an atmosphere, while similar data for the Gulf Stream at the same season between the Straits of Florida and Cape Hatteras are: Temperature 22.3° C., salinity 36.35, P_H 8. 21, and CO_2 tension 2.8. Thus the cold shore-water seems to be in a condition to absorb CO_2 from the air, while the warm Gulf Stream waters are more nearly in balance with the atmosphere. In summer, when the shore current is warmed to about 22° C., its CO_2 tension rises to be quite in balance with the atmosphere.

It is well known, from the extensive work of Blackman and Smith, that photosynthesis about doubles in effect for 10° C. rise in temperature, but the tropical waters are deficient in nitrogen and can thus support only a meager plant life in comparison with that of colder

regions. Thus, McClendon found less than 0.01 mg. of nitrogen per liter as nitrates and nitrites at Tortugas, while Raben (1910) found more than ten times these amounts in the North Sea; and, as shown by McClendon, the tropical ocean, despite its high temperature, can eliminate only a small part of its free CO_2 by photosynthesis, due to the scarcity of pelagic plant life.

Krogh (1904) calculated that if the average CO_2 tension of the ocean is the same as that of the air (about 0.0003 atmosphere), it must contain 27 times as much CO_2 as the air. Thus, if the ocean gave off one-tenth of its CO_2 to the air, the carbon-dioxide tension of the sea would sink to 0.0002 atmosphere. He found that the CO_2 in the air of Disko Island, Greenland, ranged from 0.00025 to 0.007, being high with winds from the north and west and low when the wind blew from the south and east. The turbid sea-water at Disko Island had a CO_2 tension of 0.0001 to 0.00035, while the clear water in the same region had a tension of 0.00035 to 0.0006 atmosphere, thus apparently lower than that of the surrounding air.

Also, according to Krogh, the CO_2 tension of the surface water between Cape Farewell, southern Greenland, and the Shetland Islands was distinctly lower than that of the air.

The average CO_2 tension of the air over the ocean seems to be about 0.000295, this being the mean of 51 observations made by Thorpe between Brazil and England. In 1917, however, using apparatus given to me by Professor McClendon, I tested the CO_2 tension of the air over the Pacific between Samoa and San Francisco, but there was apparently no relation between the local CO_2 tension of the air and that of the water under the air, this lack of coordination being due in all probability to the great mobility and rapid fluctuation in CO_2 tension in the air as compared with that of the water. It would apparently be necessary to obtain several thousand determinations of the CO_2 tension of air over the ocean, taken at all seasons and in all weathers, to determine its mean CO_2 tension with accuracy, but the determinations that have been made indicate that it is not far different from that of the air over the land. My average for 83 observations made during eight voyages over the tropical Pacific from 23° north to about 10° south latitude is: Temperature 27°, P_H 8.22, CO_2 tension 2.99 ten-thousandths of an atmosphere, and salinity 34.87 (range 33.96 to 35.71). Thus the tropical waters appear to have a CO_2 tension about in balance with that of the atmosphere.

If we consider the subtropical and temperate surface water 400 miles and more off the California coast and extending from 35° to 23° north latitude near Honolulu, we find for the average of 46 observations that its temperature appears to be 19.8° C., P_H 8.18, the CO_2 tension 2.51 ten-thousandths of an atmosphere, and salinity

34.53 (range 32.94 to 35.64). Thus it seems to be absorbing CO_2 from the air.

The surface water within 400 miles of the coast of California, due to upwelling of deep water in this region, seems as a whole to be about in balance with the atmosphere, although closer to shore it is doubtless giving out CO_2 into the air. Thus, my average for the eight voyages is: Temperature 13.45° C., PH 8.09, CO_2 tension 3 ten-thousandths of an atmosphere, and salinity 33.15.

We lack sufficient data for a definite statement as to whether CO_2 is on the whole passing from air to sea, or vice versa, but the surmise may seem reasonable that a balance is maintained; the absorption of CO_2 from the air by the Polar Seas being offset by its passing slowly out of the ocean over the wide area of the tropics, at least during the warmer months of the year. The temperate regions, on the other hand, stand in an intermediate relation, the water absorbing CO_2 during the winter and giving it out to the air during the summer.

TABLE 6.

Locality.	PH of sea-water.
Black Sea, surface	8.34
Black Sea, deep water	7.45
Sea of Marmora and Bosporus	8.35
Eastern Mediterranean	8.27
Western Mediterranean	8.22
Coast of Portugal	8.25
Off Scotland and Faroö Island	8.08–8.22
Southeastern part of North Sea and Skagerak	8.00–8.05

It may be of interest to compare our observations with those of Palitzsch (1911), who was the first to apply Sörensen's colorimetric methods to the study of the hyrogen-ion concentration of sea-water. Palitzsch used naphtholphthalein and phenolphthalein as indicators and tested the PH of the Black Sea, Sea of Marmora, Mediterranean, Atlantic, and North Sea in summer, with the results shown in table 6.

TABLE 7.—*Hydrogen-ion Concentration, Temperature, and CO_2 Tension of Surface Water from San Francisco, California, to Pago Pago, Samoa, Observed on S. S. "Sierra," February 21 to March 5, 1917.*

SAN FRANCISCO TO HONOLULU.

Date.	Lat.	Long.	Direction toward which wind was blowing.	Weather.	Direction toward which surface current was flowing.	Air temp.	Temp. of sea.	P_H of sea-water.	H-ion concentration of sea-water.	Calculated CO_2 tension of sea-water in terms of 0.0001 atmosphere.	Miles from San Francisco.	Miles from Honolulu.
						°C.	°C.					
Feb. 21, noon	36°05′ N.	128°38′	E., strong	Dull, overcast		16.6	12.3	8.05	0.89×10^{-8}	3.1	302	.....
Feb. 22, noon	33 32	135 09	N. to NE.	....Do.		15.4	15.4	8.17	0.676	2.4	657	.....
Feb. 23, noon	30 53	140 53	E. to SE.	Squally, rough		16.5	17.6	8.2	0.63	2.2	988	.....
Feb. 24, noon	27 49	146 28	S. to SW.	Overcast		18.3	20.1	8.23	0.59	2.4	1,334	.....
Feb. 25, noon	24 22	152 19	NE.	....Do.		21.2	21.6	8.25	0.565	2.3	1,712	.....
Feb. 26, 10 a.m.	21 25	157 25	NW.	Clear and calm		23.4	23.6	8.25	0.565	2.5	2,100	.....
HONOLULU TO PAGO PAGO, SAMOA.												
						°C.	°C.					
Feb. 27, noon	17°52′	159°13′	SSW. trade	Clear		24.7	24.2	8.25	0.565×10^{-8}	2.6	.....	220
Feb. 28, noon	12 10	161 17	WSW., strong	....Do.		25.5	25.4	8.25	0.565	2.7	.....	583
Mar. 1, noon	6 35	163 21	WSW., trade	Clear, strong wind.	Strong easterly.	26.3	26.1	8.23	0.59	2.5	.....	940
Mar. 1, 5^h20^m p.m.	5 13	163 40	WSW., trade	....Do.	....Do.	26.2	25.9	8.2	0.63	3	.....	1,020
Mar. 2, noon	1 07	165 30	W., light	Clear, smooth sea.	NW. all day.	24.7	24.2	8.17	0.676	3	.....	.....
Mar. 2, 4^h45^m p.m.	Equator.	165 50	....Do.	Clear	....Do.	24.5	24.8	8.18	0.66	2.9	.....	1,365
Mar. 3, noon	4°34′ S.	167 24	....Do.	....Do.	No current	26.3	26.4	8.2	0.63	3	.....	1,653
Mar. 3, 5 p.m.	5 49	167 45	....Do.	....Do.	....Do.	26.4	26.8	8.23	0.59	3	.....	1,728
Mar. 4, noon	10 14	169 14	....Do.	....Do.	....Do.	27.4	28.	8.25	0.565	2.6	.....	2,010
Mar. 4, 5 p.m.	11 29	170 32	....Do.	....Do.	....Do.	27.4	27.9	8.25	0.565	2.6	.....	2,085

TABLE 8.—*Hydrogen-ion Concentration, Temperature, Salinity, and CO_2 Tension of the Surface Water from Pago Pago, Samoa, to Honolulu and thence to San Francisco, California, Observed on S. S. "Ventura," Captain J. H. Dawson, April 19 to May 1, 1917.*

PAGO PAGO TO HONOLULU.

Date.	Lat.	Long. W.	Direction toward which wind was blowing.	Weather at time of observation.	Direction toward which surface current was moving.	Air temp.	Water temp.	True PH corrected for salinity.	H-ion concentration of sea-water.	Chlorine, grams in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension of sea-water in terms of 0.0001 atmosphere.
						°C.	°C.					
April 19, noon	10°15′S.	169°03′W.	SW. breeze	Raining	Westerly set	25.4	27.8	8.22	0.602×10^{-8}	19.43	35.10	3
20, noon	5 10	167 00	SW. breeze	Sunshine	Easterly	26.95	26.75	8.13	0.741	19.6	35.41	3.9
21, noon	Equator	165 05	WSW. breeze	Sunshine	Strong current to E.	25.4	24.95	8.1	0.794	19.52	35.26	4
22, noon	5°42′N.	163 12	SW. strong	Sunshine	No current	26.4	25.9	8.08	0.83	19.4	35.05	4.4
23, noon	11 19	161 05	SW. moderate	Sunshine	No current	25.4	25.35	8.21	0.616	19.14	34.58	2.9
23, 5 p.m.	12 29	160 39	SW. moderate	Sunshine	No current	25.3	25.5	8.22	0.602	19.14	34.58	2.85
24, 7h30m a.m.	15 58	159 46	SW. moderate	Sunshine	Set to W.	24.7	24.55	8.22	0.602	19.14	34.58	2.75
24, noon	17 03	159 23	WSW. breeze	Sunshine	Set to E.	24.2	24.5	8.19	0.645	19.14	34.58	3
24, 5h30m p.m.	18 33	159 00	W. breeze	Sunshine	Set to W.	23.5	24.05	8.23	0.59	.....	.....	2.6
24 5 a.m.	15 miles S. of Honolulu		Calm	Sunshine	Set strongly to E.	21.1	23.75	8.2	0.63	.....	.....	2.8

HONOLULU TO SAN FRANCISCO.

Date.	Lat.	Long. W.	Direction toward which wind was blowing.	Weather at time of observation.	Direction toward which surface current was moving.	Air temp.	Water temp.	True PH corrected for salinity.	H-ion concentration of sea-water.	Chlorine, grams in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension of sea-water in terms of 0.0001 atmosphere.
						°C.	°C.					
April 25, 6h30m p.m.	5 miles SE. of Oahu.		Calm	Sunshine	Easterly or NE.?	22.4	23.9	8.18	0.66×10^{-8}	19.34	34.94	3
26, noon	23°51′N.	153°44′W.	W. breeze	Sunshine	....Do.	22.6	23.6	8.2	0.63	19.26	34.79	2.75
27, noon	27 18	147 52	W. breeze	Overcast; no rain	Southerly	21.9	21.6	8.21	0.616	19.5	35.23	2.6
28, noon	30 29	141 50	W. breeze	Sunshine	No current	19.4	19.8	8.18	0.66	19.4	35.05	2.5
29, noon	33 39	135 34	Nearly calm	Sunshine	Northerly	16.6	16.6	8.1	0.794	18.76	33.89	3.1
30, noon	36 00	128 59	Nearly calm; water, deep blue.	Overcast; no rain	No current	16.1	14.3	8.1	0.794	18.36	33.17	2.9
May 1, 7h 30m a.m.	54 miles off Golden Gate, San Francisco; water, dark greenish-brown.		Light E. breeze.	Sunshine	Southerly	12.7	10.5	7.85	0.141×10^{-7}	18.45	33.33	5.4

TABLE 9.—*Hydrogen-ion Concentration, Temperature, and Salinity of Surface Water of the Pacific between San Francisco, California, and Pago Pago, Samoa, Observed on the Voyage of S. S. "Sonoma," J. H. Trask, Commander, June 18 to July 1, 1918.*

SAN FRANCISCO TO HONOLULU.

Date.	Lat.	Long. W.	Miles.	Time of observation.	Direction toward which wind was blowing, and force of wind by Beaufort scale.	Weather at time of observation.	Surface current, direction toward which water was drifting.	Air temp.	Water temp.	P_H corrected for salinity.	H-ion concentration of sea-water.	Chlorine, grams in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
			From San Francisco.					°C.	°C.					
June 18	5 miles S. of Farallon Islands off San Francisco.		.....	4h40m p.m.	SE., force 5.....	Sunshine.....	.....	13.7	11.9	8.05	0.89 ×10⁻⁸	18.53	33.48	3.1
19	35°52′ N.	128°30′ W.	302	Noon.....	SSE., force 5.....	....Do.....	Moderate set to ESE.	16.9	17	8.19	0.645	18.45	33.33	2.4
20	33 40	134 58	648	Do.....	SW., force 3.....	Overcast; no rain.	ENE.....	18.9	18.3	8.17	0.675	18.56	33.53	2.7
21	31 03	141 14	1,004	Do.....	Westerly, force 2	.....Do.....	No current.....	21.3	20	8.17	0.675	19.04	34.40	2.8
22	28 05	147 07	1,361	Do.....	Northerly, force 12	Sunshine.....	....Do.....	24.8	22	8.18	0.66	19.58	35.37	2.9
23	24 47	152 42	1,722	Do.....	Westerly, force 4.	Variable; no rain.	Set of about 0.5 knot per hour to NNW..	24.1	24.1	8.21	0.616	19.33	34.92	2.8
24	2 miles S. of Diamond Head, Oahu Island.		2,080	11 a.m.	WSW., force 4–5	Sunshine.....	Westerly set	25.2	25.3	8.21	0.616	19.33	34.92	2.9

TABLE 9.—*Hydrogen-ion Concentration, Temperature, and Salinity of Surface Water of the Pacific between San Francisco, California, and Pago Pago, Samoa, Observed on the Voyage of S. S. "Sonoma," J. H. Trask, Commander, June 18 to July 1, 1918*—Continued.

HONOLULU TO PAGO PAGO, SAMOA.

Date.	Lat.	Long. W.	Miles.	Time of observation.	Direction toward which wind was blowing, and force of wind by Beaufort scale	Weather at time of observation.	Surface current, direction toward which water was drifting.	Air temp.	Water temp.	P_H corrected for salinity.	H-ion concentration of sea-water.	Chlorine, grams in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
			From Honolulu.					°C.	°C.					
June 25	17°21″N.	159°20′W	251	Noon.....	WSW., force 5–6	Sunshine.....	NE. about 0.75 knot per hr	27.	26.2	8.22	0.602×10^{-8}	19.19	34.67	2.9
26	12 04	161 22	590	..Do.....	WSW., force 5...	Overcast; squally.	Weak WNW.....	28.25	27.6	8.22	0.602	19.23	34.74	3
27	7 32	162 58	869	7^h15^m a.m...	Westerly.....	Sunshine.....	Westerly.....	28	28.3	8.22	0.602	19.23	34.74	3
27	6 40	163 24	936	Noon.....	Westerly, force 3	....Do.....	WSW.....	28.6	28.6	8.22	0.602	19.23	34.74	3.05
27	5 45	163 31	986	3^h30^m p.m...	Westerly, force 3	Overcast; rain....	Easterly.....	26.5	28.3	8.18	0.66	19.14	34.58	3.45
27	4 30	164 01	1,079	5 45 p.m...	Westerly, force 3	Clear; sunshine...	....Do.....	27.1	28.4	8.18	0.66	19.23	34.74	3.5
28	2 01	165 00	1,222	8 a.m	Westerly, force 2	....Do.....	....Do.....	28	28.5	8.22	0.602	.....	.....	3
28	1 17	165 19	1,279	Noon.....	Westerly, force 1–2	....Do.....	....Do.....	28.5	28.5	8.21	0.616	.....	.....	3.1
28	0 12	165 25	1,347	4^h40^m p.m...	Westerly, force 1–2	Overcast; no rain.	....Do.....	26.4	27.9	8.18	0.66	.....	.....	3.3
28	Equator.	165 30	1,358	5 30 p.m ..	Westerly, force 1–2	....Do.....	....Do.....	26.9	27.7	8.16	0.69	19.53	35.28	3.65
29	4°23′S.	167 11	1,637	Noon.....	WNW., force 5..	Sunshine.....	Easterly, 1.25 knots per hr.	27.8	28.3	8.16	0.69	19.77	35.71	3.7
30	10 04	169 24	2,003	Noon.....	WNW., force 4...	....Do.....	WSW., about 1.25 knots per hr.	28.3	28.3	8.21	0.616	19.77	35.71	3.1

APIA, SAMOA, TO SUVA, FIJI.

								°C.	°C.					
Aug. 11	Between Savaii and Nuifoe Island.		.....	Noon.....	NW., force 2.....	Sunshine.....	Westerly; slight.....	.....	27.5	8.23	0.63×10^{-8}	19.6	35.41	2.9
12	290 miles from Apia and 206 from Suva, Fiji.		.....	Noon.....	SE., force 5.....	....Do.....	....Do.....	.....	26.6	8.23	0.63	19.6	35.41	2.8

TABLE 10.—*Hydrogen-ion Concentration, Temperature, and Salinity of Surface Water of the Pacific between Suva, Fiji, and Victoria, British Columbia, Observed on the Voyage of S. S. "Niagara," J. T. Rolls, Commander, September 6–12, 1916.*

SUVA TO HONOLULU.

Date.	Approximate latitude.	Approximate longitude.	Miles from Suva, Fiji.	Time of observation.	Direction toward which wind was blowing.	Weather at time of observation.	Surface current, direction toward which water was drifting.	Air temp.	Water temp.	True P_H corrected for salinity.	H-ion concentration of sea-water.	Grams of chlorine in 1,000 grams of sea-water.	Salinity of sea-water in grams of salts in 1,000 grams of sea-water.	CO_2 tension of sea-water in terms of 0.0001 atmosphere.
								°C.	°C.					
Sept. 6..	Between Batiki and Ngau Islands, Fiji.		57	Noon.....	Light WNW..	Clear; sunshine....	Slight westerly drift.	24.2	25.4	8.23	0.59×10^{-8}	19.47	35.17	2.75
6*.	12°46′ S.	177°00′ W.	443	....Do.....	Light westerly.	Overcast; no rain..	....Do.....	27	27.8	8.23	0.59	19.71	35.61	2.9
7..	7 06	173 35	835	....Do.....	....Do.....	....Do.....	....Do.....	27.25	28.3	8.21	0.616	19.71	35.61	3.15
8..	1 25	170 30	1,237	....Do.....	Light NW....	Sunshine.....	....Do.....	28.1	28.9	8.21	0.616	19.65	35.5	3.2
8..	Equator.	169 54	1,320	4h54m p.m.	Light WNW..	....Do.....	....Do.....	29	29.1	8.21	0.616	19.62	35.44	3.25
9..	4°36′ N.	167 08	1,634	Noon.....	Calm.....	....Do.....	Westerly during day; northerly in night of Sept. 9–10.	28.9	29.5	8.22	0.602	19.19	34.67	3.1
9..	5 45	166 56	1,696	3h45m p.m.	....Do.....	Distant showers...	....Do.....	30	29.7	8.22	0.602	18.99	34.31	3.15
9..	6 12	166 32	1,725	5 30 p.m.	....Do.....	....Do.....	....Do.....	28.9	29.5	8.22	0.602	.....	.....	3.1
10..	9 34	164 35	1,973	7 45 a.m.	Light SSW....	Sunshine.....	Westerly drift.....	28.75	29.3	8.22	0.602	18.8	33.96	3.1
10..	10 30	163 55	2,046	Noon.....	....Do.....	Overcast; showers..	....Do.....	27.6	28.3	8.22	0.602	18.89	34.13	3
10..	11 16	163 46	2,100	3 p.m.....	....Do.....	Sunshine.....	....Do.....	28.7	28.6	.....		.....	.....	.....
10..	13 25	162 30	2,146	6 p.m.....	SW breeze....	....Do.....	....Do.....	28.9	28.2	.....		.....	.....	.....
11..	16 06	161 20	2,373	8h15m a.m.	Stiff SW.....	....Do.....	....Do.....	27.1	27.4	8.21	0.616	19.47	35.17	3.1
11..	16 03	160 35	2,434	Noon.....	....Do.....	....Do.....	....Do.....	27.8	26.5	8.22	0.602	19.19	34.67	2.9
12..	10 miles S. of Honolulu, Hawaiian Islands.		2,770	7h50m a.m.	....Do.....	....Do.....	....Do.....	26.1	25.6	8.21	0.616	19.38	35.01	3

HONOLULU TO VICTORIA, BRITISH COLUMBIA.

Date.	Approximate latitude.	Approximate longitude.	Miles from Suva, Fiji.	Time of observation.	Direction toward which wind was blowing.	Weather at time of observation.	Surface current, direction toward which water was drifting.	Air temp.	Water temp.	True P_H corrected for salinity.	H-ion concentration of sea-water.	Grams of chlorine in 1,000 grams of sea-water.	Salinity of sea-water in grams of salts in 1,000 grams of sea-water.	CO_2 tension of sea-water in terms of 0.0001 atmosphere.
								°C.	°C.					
Sept. 13..	25°20′ N.	155°03′ N.	290	Noon.....	Stiff WSW....	Sunshine.....	Westerly.....	26	25.25	8.21	0.616×10^{-8}	19.53	35.28	2.9
14..	30 48	150 26	687	....Do.....	Stiff NNW....	....Do.....	Southerly.....	26.4	24.1	8.18	0.66	19.53	35.28	3.1
15..	35 45	145 05	1,090	....Do.....	N. breeze.....	....Do.....	....Do.....	22.2	22.2	8.16	0.69	19.18	34.64	3.1
16..	40 30	139 15	1,484	....Do.....	....Do.....	Overcast; no rain...	....Do.....	23.3	19.4	8.17	0.675	18.64	33.68	2.75
17..	44 40	132 20	1,880	....Do.....	N. light.....	Dense fog; no rain.	Water blue.....	19	18	8.17	0.675	18.64	33.68	2.6
18..	98 miles west of Victoria, B. C.		2,257	....Do.....	NE. light.....	Fog; no rain.....	Water dull gray-green.	14.5	13.3	8.05	0.89	17.88	32.30	3.2

* Date repeated due to crossing the 180° meridian, bound eastward.

TABLE 11.—*Hydrogen-ion Concentration, Temperature, Salinity, and CO_2 Tension of Surface Water from San Francisco, California, to Pago Pago, Samoa, Observed on the Voyage of S. S. "Sonoma," J. H. Trask, Commander, July 8–20, 1919.*

SAN FRANCISCO TO HONOLULU.

Date.	Lat.	Long., W.	Miles.	Time of observation.	Direction toward which wind was blowing.	Weather.	Direction toward which current was moving.	Air temp.	Water temp.	P_H of sea-water corrected for salinity.	Hydrogen-ion concentration of sea-water.	Grams of chlorine in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
			From San Francisco.					°C.	°C.					
July 8.	S. of Farallon Islands.			3h45m p.m.	SE., light.....	Fog; no rain.....	.....	12.4	14.7	8.17	0.675×10^{-8}	18.57	33.55	2.35
9.	35°44′ N.	128°54′	323	Noon.....	....Do.....	Overcast; no rain..	.....	15.9	16.5	8.17	0.675	18.23	32.94	2.4
10.	33 25	135 45	690	....Do.....	SW. light.....	....Do.....	.....	19.4	19.5	8.17	0.675	18.78	33.93	2.8
11.	30 36	142 08	1,057	....Do.....	....Do.....	Fog; no rain.....	.....	21.2	22.1	8.18	0.66	19.38	35.01	2.8
12.	27 27	148 03	1,423	....Do.....	WSW. light...	Clear sunshine.....	NE.....	24	23.9	8.21	0.616	19.48	35.19	2.8
13.	24 13	153 31	1,776	....Do.....	....Do.....	....Do.....	.....	25.2	25.1	8.21	0.616	19.28	34.83	2.9
14.	E. of Oahu Island.		2,065	8h20m a.m.	....Do.....	....Do.....	.....	25.5	26	8.21	0.616	19.28	34.83	3.0

HONOLULU TO PAGO PAGO, SAMOA.

Date.	Lat.	Long., W.	Miles.	Time of observation.	Direction toward which wind was blowing.	Weather.	Direction toward which current was moving.	Air temp.	Water temp.	P_H of sea-water corrected for salinity.	Hydrogen-ion concentration of sea-water.	Grams of chlorine in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
			From Honolulu.					°C.	°C.					
July 15.	17°23′ N.	159°13′	247	Noon.....	WSW. breeze.	Sunshine.....	No current.	26.3	25.6	8.22	0.602×10^{-8}	19.08	34.47	2.9
16.	11 58	161 07	590	..Do.....	WNW. breeze.	Overcast; no rain..	....Do.....	26.8	26.7	8.22	0.602	19.18	34.65	2.9
17.	7 20	.....		9 a.m.....	WNW. light...	Sunshine.....	....Do.....	28.2	28.1	8.22	0.602	18.89	34.13	3
17.	6 35	162 57	931	Noon.....	....Do.....	Overcast; no rain..	....Do.....	28.5	28.3	8.22	0.602	18.89	34.13	3
17.	5 05	.....		6 p.m.....	....Do.....	....Do.....	....Do.....	27.4	28.5	8.22	0.602	18.99	34.31	2.95
18.	2 03	.....		8 a.m.....	WNW. stiff...	Sunshine.....	....Do.....	28	28	8.22	0.602	19.19	34.67	3
18.	1 18	164 55	1,269	Noon.....	....Do.....	....Do.....	....Do.....	29.1	28.6	8.22	0.602	19.28	34.83	3.05
18.	Equator.	.....		5h40m p.m.	....Do.....	....Do.....	....Do.....	28.4	28.7	8.21	0.616	19.28	34.83	3.1
19.	4°06′ S.	166 53	1,611	Noon.....	NW. stiff.....	....Do.....	....Do.....	29.25	28.8	8.21	0.616	19.38	35.01	3.1
20.	9 57	169 14	1,984	..Do.....	....Do.....	....Do.....	Set to W....	28	28.4	8.24	0.575	19.13	34.56	2.8

TABLE 12.—*Hydrogen-ion Concentration, Temperature, Salinity, and CO_2 Tension of Surface Water between Pago Pago, Samoa, and San Francisco, California, Observed on the Voyage of S. S. "Ventura," J. H. Dawson, Commander, September 17–29, 1919.*

PAGO PAGO TO HONOLULU.

Date.	Lat.	Long., W.	Miles.	Time of observation.	Direction toward which wind was blowing.	Weather.	Direction toward which current was flowing.	Air temp.	Water temp.	P_H of sea-water corrected for salinity.	H-ion concentration of sea-water.	Grams of chlorine in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
			From Pago Pago.					°C.	°C.					
Sept. 17.	10°22′ S.	169°11′	255	Noon..	WNW. light.....	Overcast; no rain..	W., slight...	28.3	28.4	8.21	0.616×10^{-8}	19.38	35.01	3.1
18.	4 57	167 14	600	...Do...	W., very light...	....Do.....	No current..	29.4	28.8	8.21	0.616	19.38	35.01	3.1
19.	Equator.	165 41	911	9 a.m..	W. breeze.....	Clear.....	W., slight...	29	28.3	8.21	0.616	19.38	35.01	3.1
19.	0°31′ N.	165 37	942	Noon..	....Do.....	....Do.....	....Do.....	29.2	28.6	8.21	0.616	19.43	35.1	3.1
20.	6 05	163 52	1,292	...Do...	WSW., light.....	....Do.....	....Do.....	29.3	29.4	8.22	0.602	19.1	34.51	3.1
21.	11 40	162 42	1,651	...Do...	SSE., light.....	Overcast; no rain..	....Do.....	27.2	27.7	8.22	0.602	18.99	34.31	3
21.	12 06	162 35	1,695	4 p.m..	....Do.....	Clear.....	W., strong..	27.8	27.9	8.24		19.04	34.4	2.75
22.	17 03	159 38	1,998	Noon..	W., nearly calm.	....Do.....	....Do.....	26.5	26.5	8.21	0.616	19.38	35.01	3
HONOLULU TO SAN FRANCISCO.														
			From Honolulu.					°C.	°C.					
Sept. 24.	23°49′	153°41′	283	Noon..	WSW., brisk....	Clear.....	No current..	26.3	25.6	8.21	0.616×10^{-8}	.....	.....	.....
25.	27 07	148 01	650	...Do...	SSE., light.....	Overcast; no rain..	....Do.....	24.6	24.4	8.2	0.63	19.73	35.64	2.9
26.	30 24	142 06	1,020	...Do...	WSW., light.....	Clear.....	....Do.....	22.1	22.9	8.18	0.66	19.48	35.19	2.9
27.	33 14	135 53	1,381	...Do...	....Do.....	....Do.....	....Do.....	21.3	20.5	8.17	0.675	18.94	34.22	2.9
28.	35 46	129 22	1,739	...Do...	S., light.....	....Do.....	....Do.....	17.2	18.4	8.17	0.675	18.44	33.31	2.7
29.	50 miles W. of Farallon Islands			8 a.m..	NW., light.....	....Do.....	.....	14.6	15	8.17	0.675	18.58	33.57	2.4

TABLE 13.—*Hydrogen-ion Concentration, Temperature, Salinity, and CO_2 Tension of the Surface Water of the Pacific between San Francisco, California, and Pago Pago, Samoa, Observed on S. S. "Sonoma," J. H. Trask, Commander, March 21 to April 1, 1920.*

Date.	Lat.	Long. W.	Miles.	Time of observation.	Direction toward which wind was blowing.	Weather at time of observations.	Direction toward which surface current was moving.	Air temp.	Water temp.	PH corrected for salinity.	H-ion concentration of sea-water.	Grams of chlorine in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
SAN FRANCISCO TO HONOLULU.														
			From San Francisco.					°C.	°C.					
March 21.	36°22′N	127°19′	238	Noon..	NNE.	Rough; overcast.....	.....	13.5	13.25	8.2	0.63×10^{-8}	18.4	33.24	2.2
22.	34 10	133 17	560	...Do...	SE.	Rough.....	.....	13.2	14.3	8.23	0.59	18.55	33.51	2
23.	31 10	139 21	918	...Do...	SW.	Clear.....	.....	15.8	17.1	8.22	0.602	19.29	34.85	2.2
24.	28 21	145 38	1,287	...Do...	WSW.	Moderate.....	.....	17.7	19.4	8.22	0.602	19.68	35.55	2.3
25.	25 17	151 30	1,659	...Do...	NW.	Overcast, moderate.	.....	20.7	21.9	8.24	0.575	19.53	35.28	2.3
26.	21 48	157 05	2,026	...Do...	SW.	Clear and moderate.	.....	23.6	24.2	8.24	0.575	19.33	34.92	2.6
HONOLULU TO PAGO PAGO, SAMOA.														
			From Honolulu.					°C.	°C.					
March 27.	18°25′N.	158°57′	184	Noon ..	Calm.	Clear.....	.....	25.4	25	8.25	0.565×10^{-8}	19.28	34.83	2.6
28.	12 17	161 18	575	2 p. m..	NE.	Overcast; no rain....	W.	26.7	25.4	8.25	0.565	18.97	34.27	2.6
29.	7 09	163 13	905	Noon ..	SW.	Clear, moderate.....	W. all day.	27.9	27.2	8.25	0.565	19.18	34.65	2.7
30.	1 31	165 11	1,264	...Do...	NW.	Clear, moderate.....	Do.	27.4	26.9	8.2	0.63	19.29	34.85	3
31.	4°32′S.	167 27	1,651	...Do...	SW.	Clear, light breeze...	S.	29.2	29.1	8.2	0.63	19.58	35.37	3.2
April 1.	10 27 S.	169 14	2,022	...Do...	SW.	Clear, light breeze...	W.	30.8	29.5	8.24	0.575	18.97	34.27	3.2
SAMOA TO SUVA, FIJI, IN S. S. NAVUA.														
								°C.	°C.					
April 11.	Between Upolu, Samoao and Vavau, Tonga.			Noon..	WNW.	Overcast; rough; no rain.	.....	29.6	28.5	8.23	0.59×10^{-8}	19.55	.35.32	3
15.	19°36′S.	178°34′ Between Vatoa and Totoya, Fiji.	.....	.....	WNW.	Smooth; light breeze; clear.	.....	28.4	27.3	8.24	0.575	19.84	35.84	2.9

TABLE 14.—*Hydrogen-ion Concentration, Temperature, Salinity, and CO_2 Tension of Surface Water between Pago Pago, Samoa, and San Francisco, California, July 29 to August 3, and August 19 to 24, 1920.*

PAGO PAGO TO HONOLULU.

Date.	Lat.	Long. W.	Miles.	Time of observation.	Direction toward which was blowing.	Weather.	Direction toward which current was flowing.	Air temp.	Water temp.	P_H of water corrected for salinity.	H-ion concentration of sea-water.	Grams of chlorine in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
			From Pago Pago.					°C.	°C.					
July 29	9°41′ S.	168°55′	299	Noon.	SW. light....	Clear.....	No current.....	29	28.9	8.23	0.59×10^{-8}	19.33	34.92	2.9
30	4 08	167 06	640	Do.	...Do.....	....Do.....	....Do.....	28.6	28.4	8.23	0.59	19.48	35.19	3
31	1 18 N.	165 18	984	Do.	WSW. light..	....Do.....	....Do.....	27.5	27.7	8.21	0.616	19.28	34.83	3
Aug. 1	6 44	163 40	1,425	Do.	SW. light....	Overcast.....	Strong easterly all day since 8 a. m.....	28.5	28.2	8.24	0.575	19.10	34.51	2.9
2	12 17	161 43	1,777	Do.	SW. fresh....	Clear.....	Westerly since 4 a. m.....	27.9	26.8	8.24	0.575	18.91	34.16	2.8
3	17 24	159 38	2,107	Do.	...Do.....	....Do.....	Westerly.....	26.7	26.1	8.24	0.575	19.04	34.40	2.75

HONOLULU TO SAN FRANCISCO.

Date.	Lat.	Long. W.	Miles.	Time of observation.	Direction toward which was blowing.	Weather.	Direction toward which current was flowing.	Air temp.	Water temp.	P_H of water corrected for salinity.	H-ion concentration of sea-water.	Grams of chlorine in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
			From Honolulu.					°C.	°C.					
Aug. 19	23°37′ N.	154°01′	257	Noon	SW. fresh....	Overcast, no rain.	.....	26.1	25.8	8.24	0.575×10^{-8}	19.18	34.65	2.7
20	26 37	149 26	565	Do.	...Do.....	....Do.....	.....	25.2	24.8	8.23	0.59	19.23	34.74	2.7
21	29 18	144 22	879	Do.	SW. light....	....Do.....	.....	24	23.6	8.21	0.616	19.44	35.12	2.7
22	31 58	139 00	1,200	Do.	WSW. light..	....Do.....	.....	22.1	22	8.22	0.602	19.03	34.58	2.6
23	34 19	133 10	1,527	Do.	SSW. light...	....Do.....	.....	20.2	20.6	8.2	0.63	18.64	33.68	2.6
24	36 23	127 01	1,854	Do.	...Do.....	....Do.....	.....	17.6	16.7	8.21	0.616	18.06	32.63	2.2
	226 miles from San Francisco.													

TABLE 15.—*Hydrogen-ion Concentration, Temperature, and Salinity of Surface Water along the Coast between Nova Scotia and Tortugas, Florida.*

Date.	Lat. N.	Long. W.	Locality.	Time of observation.	Direction toward which wind was blowing.	Weather.	Color of water.	Air. temp.	Water temp.	P_H of sea-water corrected for salinity.	H-ion concentration of sea-water.	Chlorine, grams in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
								°C.	°C.					
1918 Dec. 28	40° 7′	73°54′	20 mi. S. of Sandy Hook, 6 mi. off N. J. coast.	2h30m p.m.	Light SE...	Clear.....	Dull dark greenish brown.	2	6.7	8.05	0.89×10^{-8}	17.39	31.42	2.5
29	36 02	75 26	11 mi. off Albemarle Sound, N. C.	Noon.....	.... Do.....	....Do....	Dull green.....	6.4	10.2	8.05	0.89	17.93	32.39	2.95
29	35 1	75 27	15 mi. off Cape Hatteras, N. C.	4h30m p.m.	.... Do.....	.... Do....	Dull green; no gulf weed.	8	14.7	8.14	0.725	18.51	33.44	2.6
30	32 32	79 02	35 mi. off Charleston Light-Ship.	Noon	Light S.....	....Do....	Blue, with gulf weed.	12	19.5	8.2	0.63	20.03	36.18	2.5
31	28 29	80 21	10 mi. off Cape Canaveral, Fla.	....Do	Light SE...	....Do....	Dull green, with some gulf weed in it.	24	21.1	8.14	0.725	20.13	36.36	3.3
1919 Jan. 1	24 33	81 3	3 mi. off Sombrero Light, Florida Reef.	....Do	.... Do.....	....Do....	Deep blue water.	25.2	24.4	8.2	0.63	20.15	36.4	2.9
15	24 38	82 56	Loggerhead Key, Tortugas, Fla.	8h30m a.m.	Calm	....Do....	Deep blue.....	19	20.6	8.2	0.63	20.1	36.31	2.65
21	25 22	80 13	Hawk Channel, near Old Rhodes Key, Fla.	5 00 p.m.	Calm after a strongSW. breeze.	....Do....	Gulf weed and *Physolia* in blue water.	23	22.5	8.2	0.63	19.99	36.11	2.8
24	30 35	81 10	10 mi. N. of St. Johns River, Fla.	5 00 p.m.	Calm	Overcast; no rain.	Dull green.....	15	13.6	8.1	0.794	17.75	32.07	2.8
25	32 44	79 45	2 mi. off Charleston, S. C., buoy.	10 30 a.m.	.... Do.....	....Do....	....Do.....	13.8	13	8.16	0.692	17.4	31.44	2.35
25	33 5	78 38	43 mi. off Cape Romain.	4 00 p.m.	Light SE. breeze.	....Do....	Light blue-green, with gulf weed.	17.2	17	8.21	0.616	19.91	35.97	2.3
26	35 27	75 18	20 mi. N. of Diamond Shoal, Cape Hatteras.	8 40 a.m.	NW. breeze.	....Do....	Dull green; no gulf weed in it.	13.7	13.2	8.11	0.775	17.6	31.8	2.5
26	36 10	75 22	17 mi. off Albemarle Sound, N. C.	Noon	S. breeze....	....Do....	Dull green.	9	8.2	8.14	0.725	17.1	30.9	2.1
27	40 12	73 53	13 mi. S. of Scotland Light-ship, coast of New Jersey.	8h00m a.m.	NW. wind..	Clear.....	Rosin-colored water.	4	5.7	8.08	0.83	17.44	31.51	2.25
1918 Feb. 13	38 11	74 40	24 mi. off coast of Maryland.	10 30 a.m.	Calm	Overcast; no rain.	Dull rosin-green.	.....	2.8	8.05	0.89	18.11	32.72	2.25
14	34 10	76 30	25 mi. S. of Cape Lookout, N. C.	10 30 a.m.	.... Do.....	....Do....	Dull gray-green.	.....	7.8	8.04	0.91	17.03	30.77	2.75
15	31 25	80 22	43 mi. off Sapelo Sound, Ga.	11 00 a.m.	.... Do.....	....Do....	....Do.....	.....	1.3	8.15	0.71	19.77	35.71	2.3

TABLE 15.—*Hydrogen-ion Concentration, Temperature, and Salinity of Surface Water along the Coast between Nova Scotia and Tortugas, Florida*—Continued.

Date.	Lat. N.	Long. W.	Locality.	Time of observation.	Direction toward which wind was blowing.	Weather.	Color of water.	Air. temp.	Water temp.	P_H of sea-water corrected for salinity.	H-ion concentration of sea-water.	Chlorine, grams in 1,000 grams of sea-water.	Salinity, grams of salts in 1,000 grams of sea-water.	Calculated CO_2 tension in terms of 0.0001 atmosphere.
								°C.	°C.					
1918 Feb. 15	30°20′	80°28′	48 mi. off St. Johns River, Fla.	5h 30m p.m.	Calm.....	Clear.....	Dull blue.....	.....	20.2	8.14	0.725×10^{-8}	20.01	36.15	3.2
16	27 00	80 00	5 mi. off shore, Jupiter Inlet, Fla.	10 15 a.m.	....Do....	....Do....	Deep blue.....	.....	22	8.17	0.675	20.04	36.2	3
18	24 32	81 00	6 mi. off Sombrero Light, Florida Reef.	2 45 p.m.	SE. breeze.	....Do....	....Do.....	.....	22.5	8.19	0.645	19.87	35.9	2.9
19	29 17	79 55	57 mi. E. of Daytona, Fla.	Noon.....	SE. wind...	Overcast; no rain.	Blue.....	.....	17.9	8.04	0.645	19.87	35.9	2.5
1919 Mar. 25	42 25	70 30	10 mi. off Thatcher's Island, Cape Ann, Mass.	3h50m p.m.	SE. breeze.	Clear, sunshine.	Dark green.....	5.7	4.3	8.04	0.91	17.56	31.73	2.3
25	42 40	69 52	47 mi. from Boston Harbor.	5 50 p.m.	....Do....	....Do....	....Do.....	6.4	4.2	8.0	1.0	18.01	32.54	2.65
25	42 52	68 53	Cash's Ledge, Gulf of Maine.	8 50 p.m.	....Do....	Clear, starlight.	.....	5.4	3.5	8.0	1.0	17.91	32.36	2.6
26	43 45	66 17	8 mi. off Yarmouth Light, Nova Scotia.	4 50 a.m.	....Do....	Clear.....	Dark green.....	2.4	1.4	7.96	0.1×10^{-7}	17.53	31.67	2.75
26	43 36	66 47	32 mi. off Yarmouth Light, Nova Scotia.	8 35 p.m.	....Do....	....Do....	....Do.....	4.6	2.2	7.96	0.1	17.41	31.46	2.8
1919 May 10	37 20	74 18	42 mi. off coast of Virginia.	Noon.....	WNW. strong.	Cloudy; showers.	Dull green; no gulf weed.	15.8	12.5	8.04	0.91×10^{-8}	18.94	34.22	3.25
11	33 26	75 35	97 mi. E. of Frying Pan Shoals Light Ship, S. C.	....Do.....	Light NE. 1–4 Beaufort scale.	Clear.....	Blue, with gulf weed in it.	23.8	25.3	8.21	0.616	19.71	35.61	2.9
12	29 58	79 27	94 mi. E. of St. Augustine, Fla.	....Do.....	Lt. WNW.	....Do....	....Do.....	25.9	24.9	8.22	0.602	20.08	36.27	2.8
13	26 45	80 00	2 mi. off Palm Beach, Fla.	....Do.....	Calm.....	....Do....	....Do.....	26.5	25.6	8.19	0.645	20.08	36.27	3.1
23	24 38	82 55	Tortugas, Fla.	....Do.....	Light SW.	....Do....	Blue; no gulf weed.	26.7	26.1	8.17	0.675	20.08	36.27	3.3
1919 June 22	26 04	80 00	About 7 mi. off Snake River, Fla.	....Do.....	....Do....	....Do....	Blue, with gulf weed.	27.6	28.1	8.2	0.63	19.72	35.62	3.2
24	35 01	75 22	0.5 mi. E. of Diamond Shoal Light Ship.	10h40m a.m.	Light NW.	Cloudy; no rain.	Dull blue, with much gulf weed.	25	24.75	8.18	0.66	18.11	32.72	3.1
24	35 35	75 20	34 mi. N. of Diamond Shoal Light Ship.	2 30 p.m.	....Do....	....Do....	Dull green; no gulf weed.	24.5	22.3	8.07	0.85	16.44	29.7	4
25	39 45	73 55	6 mi. off Barnegat, N. J.	10 15 a.m.	....Do....	....Do....	Dull green-gray.	22.9	19.5	8.06	0.87	16.78	30.32	4.2

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EXPLANATION OF THE CHARTS.

The charts show the PH, temperature in degrees centigrade, and salinity of the surface water in grams of total salts in 1,000 grams of sea-water. Thus 8.05–11.9°–33.48 June 18 means that the PH was 8.05, temperature 11.9° C., salinity 33.48 grams of total salts in 1,000 grams of sea-water, and date June 18. Currents are indicated by ARROWS.

These charts represent results obtained on four voyages over the Pacific between Samoa, or Fiji, and San Francisco, or Vancouver, British Columbia, and five voyages over the Atlantic ranging from Nova Scotia to Trinidad, British West Indies. They are intended to give a graphical representation of the characteristic temperature, PH, and salinity in these regions.

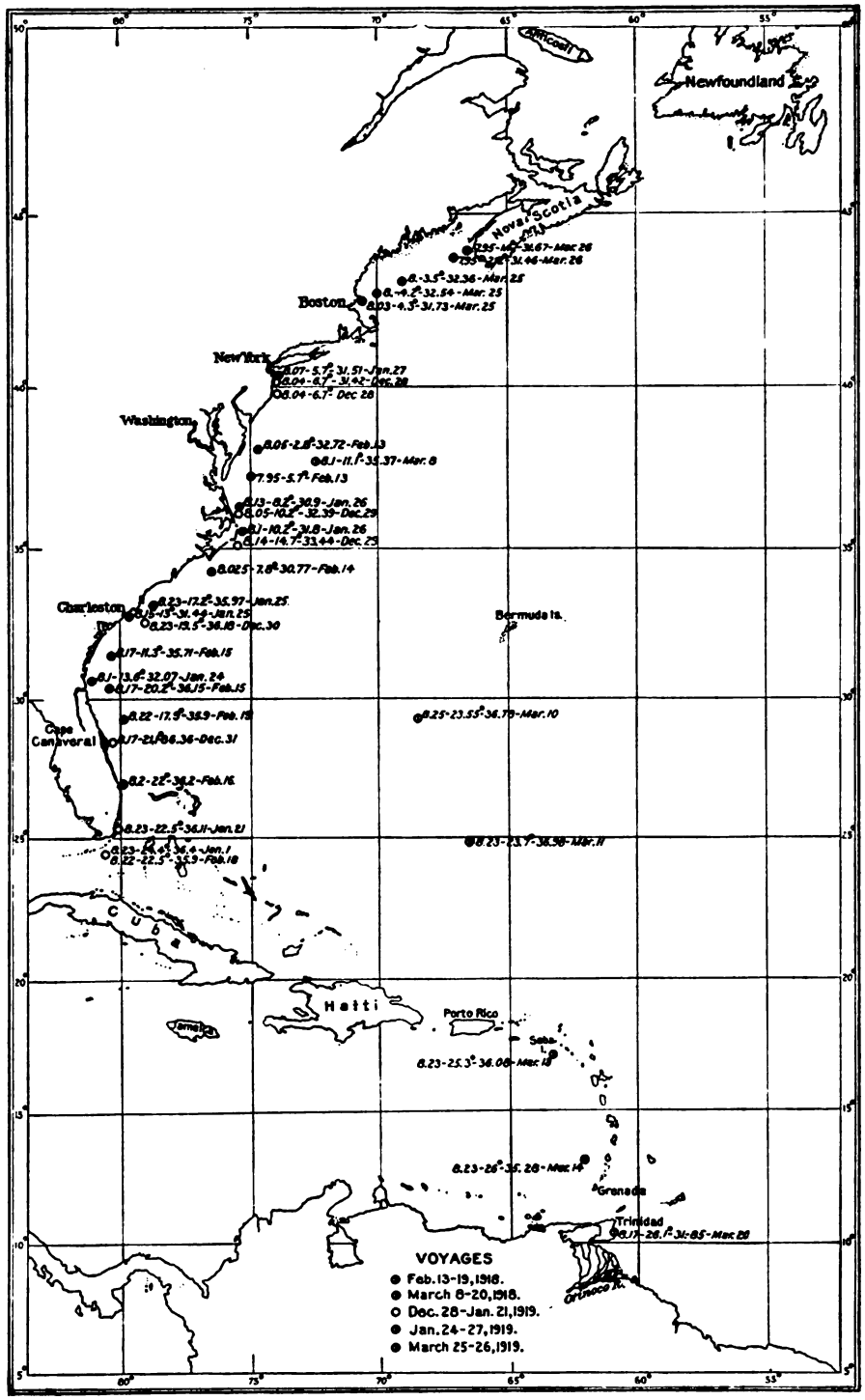
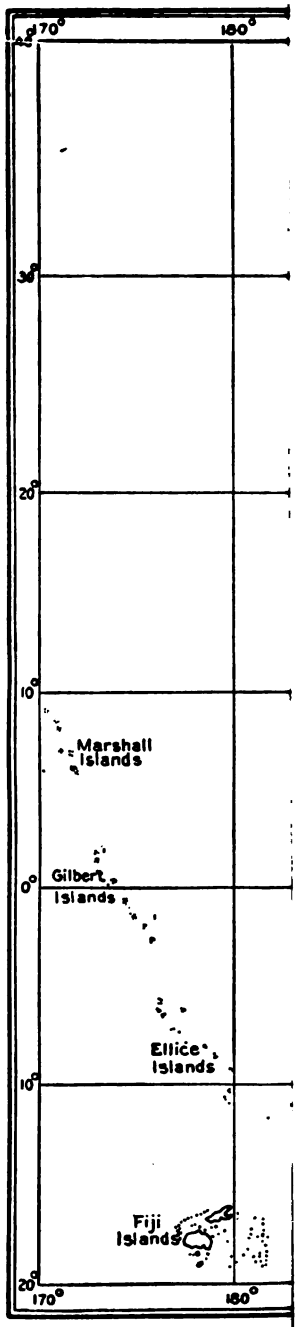
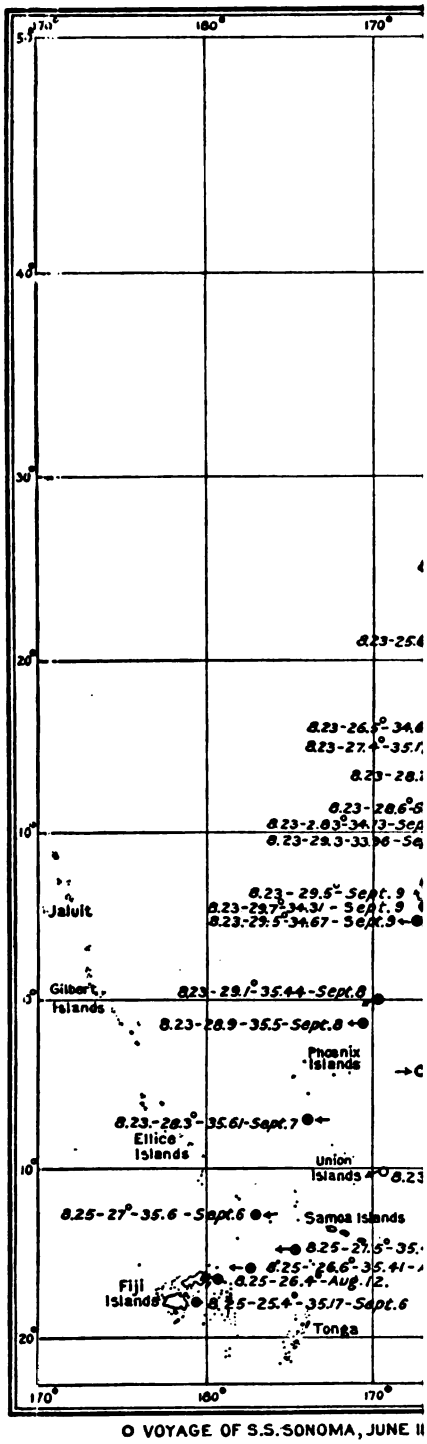


CHART 1.—VOYAGES IN ATLANTIC OCEAN, 1918 AND 1919.


170°
180°
30°
20°
10°
Marshall Islands
0°
Gilbert Islands
Ellice Islands
10°
Fiji Islands
20°
170°
180°

O VOYA



O VOYAGE OF S.S. SONOMA, JUNE 1

IV.

CARBON-DIOXIDE CONTENT OF SEA-WATER AT TORTUGAS.

By ROGER C. WELLS.

One figure.

CARBON-DIOXIDE CONTENT OF SEA-WATER AT TORTUGAS.[1]

By Roger C. Wells.

INTRODUCTION AND SUMMARY OF RESULTS.

It is generally considered that the carbon-dioxide content of sea-water may be increased by accessions from the air, by animal life, by the decay of organic matter in the sediments on the bottom or elsewhere, by the solution of carbonate rocks, by the contributions of rivers, and by gas vents beneath the sea. Although all rivers carry carbon dioxide into the sea, most of them actually dilute the sea-water, and should, therefore, as a matter of fact, not be classed as increasing the concentration of the carbon dioxide in sea-water. On the other hand, sea-water may lose carbon dioxide to the air, to plants, and in the formation of carbonate rocks and the carbonaceous parts of organisms. Mere evaporation and precipitation also alter the carbon-dioxide concentration somewhat if other conditions remain unchanged. It is obvious that the actual condition of the water at any given time and place depends on a complex set of factors whose evaluation requires many observations as well as a knowledge of the previous history of the water, including information concerning the currents, flora, fauna, and other agencies that may affect it.

With the hope of gaining information on some of these points, the writer has made determinations on sea-water from various localities, which supplement to some extent the work of Schlösing (1880), Dittmar (1884), Murray (1889), Fox (1909), McClendon (1918), and Mayor (1919).

Determinations were made at Tortugas, Florida, in June 1919,[2] on water taken directly from the sea at various points about Loggerhead Key, which reveal unmistakable diurnal variations, first noted by McClendon in 1916.[3] The water has sufficient contact with plants and sea-weeds to show the effect of photosynthesis on its CO_2 content. There is a loss of CO_2 by day and a gain by night. The respiration of the animals is not sufficient to keep the equilibrium steady during the day. It is impossible to say to what extent the balance is maintained by the atmosphere, but in this locality, at least, where the water is

[1] Published by permission of the Director, United States Geological Survey.
[2] Carnegie Inst. Wash. Year Book for 1919, p. 195.
[3] Carnegie Inst. Wash. Publication No. 252, p. 216 (1918).

relatively shallow, plant life appears to be the chief agency in causing a daily variation in the CO_2 content, and also a slight deficit in the average content from the theoretical. Even here, however, the departure from the equilibrium conditions required by the equation of Fox, which is based entirely on the physical factors of temperature and salinity, is not great. It is to be inferred that the slight deficit in CO_2 is accompanied by an excess of oxygen in the water, increased activity in the animal-vegetable cycle, and increased precipitation of calcium carbonate.

The diurnal changes caused by photosynthesis are in the same direction as those caused by the diurnal temperature changes, assuming complete adjustment of the equilibrium between the carbon dioxide in the water and that in normal air. This equilibrium can scarcely reach a full adjustment each day, however, even in the relatively shallow water of the lagoon, but if it did it would not account for all of the observed variation in carbon-dioxide content. Theoretically, all surface sea-water should show slight diurnal changes in its gas content, but the mixing of the water and experimental errors have heretofore prevented the demonstration of such changes.

I have attempted to discover whether Dole's figures[1] on total carbon dioxide at Tortugas reveal diurnal changes, but unfortunately the data were gathered solely with reference to the tides and do not give the time of day exactly, so that it is impossible to use them for this purpose. As far as can be determined, there is no general correlation with the tidal flow, but if the effects of photosynthesis were considered, it is possible that some relationship to the tides could be determined. However, as photosynthetic action extends to considerable depths, it appears doubtful whether unaltered water gains access to Tortugas by tidal action, the keys being situated on the western part of the Florida platform. There is thus no opportunity for an up-welling of deep water rich in CO_2, as noted by Mayor in the open water of the Pacific. The source of the water in the flowing tides should be determined, if possible, at the time further samples are taken to test these points. Wood-Jones has shown how markedly the whole development of the Cocos-Keeling Islands is affected by the prevailing winds and currents of the open Indian Ocean.

The average diurnal variation in CO_2 found around Loggerhead Key was about 4.3 per cent of the total CO_2. There was greater variation than this on some days, as much as 5.6 per cent. Moreover, the absolute quantities of CO_2 found varied from day to day, the mean being 0.0895 gram per liter at 27.2° C. On one rainy, cloudy day the CO_2 found averaged 0.091 gram per liter, whereas on a fine day it averaged 0.0885. This is as would be expected with regard to the photosynthetic effect of sunlight, but the data are still too few

[1] Carnegie Inst. Wash. Publication No. 182, p. 73 (1914).

to establish the relationship definitely. Even wider differences are shown in Dole's figures on different days. No diurnal variations were found in the excess base, and it is doubtful whether any will be, as solution and precipitation of carbonates from sea-water are not thought to be an action that reaches equilibrium rapidly. Even the final CO_2 distribution attained between sea-water and air appears to be reached slowly, according to the experimental evidence at present available.

Determinations of CO_2 should probably be made soon after the time the samples are collected, on account of the possibility of the decay of organic matter, such as algæ, in preserved samples. Moreover, the writer[1] has shown that sea-water preserved for a long time in glass loses part of its CO_2, owing to the precipitation of aragonite brought about by the slow solution of alkali from the glass. This was ordinary glass. It is well known that "nonsol" glass is attacked more slowly. The other change found accompanying the decrease in CO_2 was a decrease in the titration alkalinity of the water, corresponding to the decreased quantities of carbonate and bicarbonate, but the P_H value was not greatly changed, as sodium had merely taken the place of calcium.

The average "excess base" found at Tortugas corresponds to a normality of 0.00239. This titration includes everything that consumes acid; it represents chiefly bicarbonate, about 0.00183, some carbonate, about 0.00041, and other substances that contribute to the alkalinity, about 0.00015. The last figure, however, was not determined at Tortugas, but with Gulf Stream water that had been shipped to Washington. This water was collected November 30, 1919, temperature 17.94° C., lat. 24° 24′ 20″ north, long. 81° 31′ 15″ west, about 7.5 miles from American Shoal Light, depth 105 meters. Its titration alkalinity, or excess base, was 0.00258, total CO_2 0.0968 gram per liter, P_H 8.08 at 25° C. These figures give on calculation bicarbonate alkalinity 0.00197, carbonate alkalinity 0.00046, other alkalinity 0.00015. The observations here reported are too few, however, to warrant discussion.

The methods used in arriving at these figures are given below.

METHODS.

Carbon dioxide.—The total CO_2 was determined by adding an excess of hydrochloric acid to 500 c.c. portions of the water and boiling about 15 minutes, while a current of CO_2 free air was passed through the water, then over calcium chloride, and finally through two soda-lime tubes, each having its last third part filled with calcium chloride. The soda-lime tubes were weighed with a counterpoise to minimize errors likely to be caused by the high humidity. The second tube served as a check on the absorbing power of the first.

[1] Jour. Wash. Acad. Sci., 10, 249 (1920).

Chloride.—The chloride was titrated with silver nitrate, using potassium chromate as indicator, and the density of the water was calculated with the aid of Knudsen's tables.

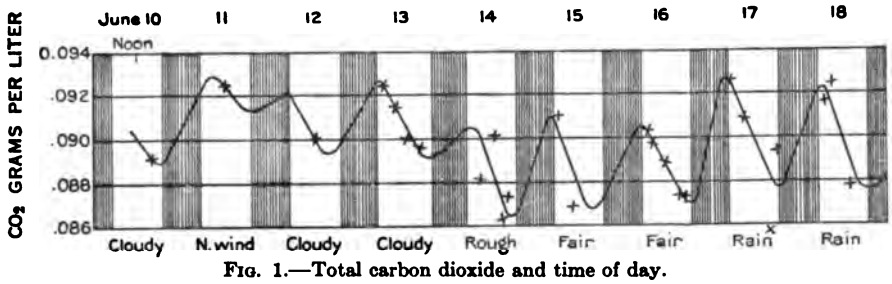


FIG. 1.—Total carbon dioxide and time of day.

H-ion concentration.—The PH values were estimated colorimetrically by comparison with a set of standard tubes very kindly loaned by Professor J. F. McClendon.

Excess base.—The excess base was obtained by titrating 100 c. c. portions with 0.02 normal sulphuric acid, using methyl red as indicator and blowing out the carbon dioxide by means of pure air for

TABLE 1.—*Determinations on Sea-Water at Loggerhead Key, Tortugas, June 1919.*

[*t*, temperature, °C.; *Cl*, chlorine, grams per kilogram; *D*, density; PH, hydrogen-ion concentration expressed as —log [H+]; *Alk.*, excess base, in terms of a normal solution, or alkalinity titrated with acid, using methyl red and blowing out CO_2; CO_2, total, gram per liter.]

	Date, time, and condition of water.	*t*	*Cl*	*D*	PH	*Alk.*	CO_2
1	June 10, 3^h30^m p.m.; cloudy...	26.6	20.01	1.02373	.....	.....	0.0890
2	11, 12 noon; fair.....	27.6	20.00	1.02339	.....	0.002370	.0925
3	11, 5^h30^mp. m.; cloudy...	28.2	20.05	1.02326	.....	.002368	.....
4	12, 12 noon; after rain....	27.4	19.90	1.02332	8.23	.002398	.0902
5	13, 6^h45^m a.m.; after rain.	27.1	19.28	1.02258	8.19	.002394	.0924
6	13, 9 50 a.m.; cloudy...	27.1	19.90	1.02342	8.19	.002394	.0913
7	13, 12 50 p.m.; cloudy...	27.5	20.07	1.02352	8.21	.002410	.0900
8	13, 4 10 p.m.....	27.6	19.96	1.02334	8.20	.002402	.0897
9	14, 9 45 a.m.; after rain and wind.....	27.0	19.89	1.02344	8.19	.002406	.0881
10	14, 3^h45^m p.m.; wind.....	27.4	19.87	1.02328	8.22	.002402	.0863
11	14, 5 15 p.m.; wind.....	27.8	20.00	1.02333	8.21	.002412	.0873
12	15, 6 30 a.m.; wind.....	26.5	19.94	1.02366	8.21	.002435	.0910
13	15, 11 a.m.....	26.8	19.31	1.02371	8.21	.002424	.0869
14	16, 7^h10^m a.m.; fair.....	26.8	19.99	1.02368	8.07	.022368	.0904
15	16, 8 15 a.m.; fair.....	27.0	20.00	1.02359	8.19	.002414	.0896
16	16, 11 a.m.; fair.....	27.0	19.99	1.02357	8.20	.002440	.0888
17	16, 4^h15^m p.m.; fair.....	28.1	20.05	1.02330	8.23	.002374	.0873
18	16, 5 45 p.m.; fair.....	27.8	19.98	1.02330	8.21	.002410	.0873
19	17, 6 30 a.m.....	27.1	19.99	1.02354	8.20	.002414	.0928
20	17, 10 15 a.m.; slightly cloudy.....	27.3	20.09	1.02361	8.18	.002396	.0910
21	17, 4^h45^m p.m.; rainy....	26.8	19.16	1.02239	8.20	.002306	.0857
22	17, 7 p.m.; after rain.....	27.6	19.77	1.02308	8.19	.002326	.0893
23	18, 7^h15^m a.m.; after shower.....	26 8	20.04	1.02370	8.18	.002418	.0918
24	18, 11 a.m.; rain.....	26.8	19.81	1.02339	.....	.002400	.0928
25	18, 1 p.m.; rain.....	26.6	19.73	1.02334	.....	.002374	.0879

15 to 20 minutes. This method gives sharp results, but the alkalinity thus found probably includes a small amount due to substances other than carbonates.

For the alkalinity due to carbonates alone the method at present used by the writer is as follows: A slight excess of 0.02 normal sulphuric acid is added from a burette to 100 c. c. of sea-water in a nonsol flask. The mixture is then boiled 15 to 20 minutes, while a gentle stream of pure air is passed into it to assist in blowing out the carbon dioxide. (This step might be done under reduced pressure.) The solution is then titrated back with 0.02 normal sodium hydroxide, using cresol red (o-cresolsulphonephthalein) as indicator. This indicator is not entirely satisfactory, but is used in order to arrive at an end point of approximately the same PH value as sea-water. If this end point is not used the titration will include in part the acidification of certain substances besides carbonates that are present in sea-water. The water is first more than acidified in order to assure the removal of all carbon dioxide.

The record of determinations made at Tortugas is given in table 1. Figure 1 shows the relation between the carbon-dioxide content of the water and time of day.

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V.

ANALYTICAL SEARCH FOR METALS IN TORTUGAS MARINE ORGANISMS.

By ALEXANDER H. PHILLIPS,

Princeton University.

ANALYTICAL SEARCH FOR METALS IN TORTUGAS MARINE ORGANISMS.

By Alexander H. Phillips.

This is the second instalment of analyses of marine organisms collected at the Tortugas. The first was printed in the report of the Carnegie Institution of Washington for 1917, where also the general method of analyses was described. Owing to the smaller amounts of both copper and zinc in these specimens, the method was modified and the copper was determined by the ferrocyanide colorimetric method, and zinc was determined by the terbidimetric method described by Victor Berckner.[1]

Specimen.	Name.	Weight fresh.	Weight dried at 110.	Copper.	Zinc.	Iron.	Manganese as Mno.
No.		*gms.*	*gms.*				
614-O....	Plexaura homomala.....	1055	398	0.0006	0.0016	0.0021	0.00021
614-S....	Gorgonia flabellum.....	550	288	.00025	.0025	.0032	.00024
614-T....	Pseudoplexaura crassa...	1205	418	.00022	.00023	.0043	.00029
614-U....	Plexaura flexuosa	400	172	.00024	.00024	.0043	.00015
614-A-B..	Eunicea crassa	110	98	.00014	.00052	.0026	.00012
614-A-R..	Eunicea rissoæ	560	260	.00018	.00066	.0034	.00008
614-Q....	Briarium	1235	461	.00009	.00045	.0036	.00014
614-B-H..	Xiphigorgonia amceps...	445	190	.00008	.00148	.0032	.00011
614-A-W.	Gorgonia acerosa	480	141	.00012	.00208	.0060	.00019
614-W...	Bryozoa			.00014	.00084	.00196	.00021
614-C-A..	Toxopneustes			.00016	.00046	.0026	.00009
614-A-C..	Mellita	1205	717	.00032	.00042	.00015	.00065
614-A-E..	Clypeaster	1345	698	.00026	.00027	.0032	.00072
614-A-D..	Clypeaster.....	1955	956	.00022	.00034	.0036	.00046
614-B-W.	Diadema	*	97	.00021	.00006	.0028	.0002
614-B-A	Astrospecten.....	255	127	.00029	.00092	.0032	.00041
614-C....	Cassiopea xamachana ...	10370	472	.00021	.00062	.00016	.00013
614-B-F..	Pentaceras.....	1175	402	.00036	.00056	.0029	.00037
614-A-1†.	Holothuria bermudiana..	1945	404	.00012	.00034	.00072	.00021
614-A-2‡.	Holothuria bermudiana..	725	74	.00011	.00064	.0031	Trace.
614-AA-2.	Loggerhead sponge.....			.00013	.00094	.0015	.0030
620-a-4...	Unio	3623	280	.00026	.0032		
615-A-1..	Mud from Marquesas, Fla.			.0032	.0018	.0261	.0058

* Not weighed.
† Composed of the body walls, muscles, etc.
‡ Composed of organs and intestine only.

The weight of the sample taken for the determination of copper and zinc was in each case 20 grams of the material, dried at 110° C. to

[1] Jour. Bio. Chem. Soc., June 1919.

constant weight, and the amounts of all the metals, reported in the table above, are in each case expressed in grams per 20-gram sample.

The four metals sought occur in all the samples analyzed, but not in as large amounts as in those forms where it is possible to separate the soft tissues from the calcareous skeleton. In some of the present material the calcareous skeleton was by far the larger part, by weight, of the sample taken for analysis, thus reducing the amount of each metal reported in the 20-gram sample, as there is no doubt that the metals here reported are associated to a much greater extent with the soft tissues than with the calcareous skeleton.

From a consideration of the amounts of each metal reported in the various organisms, there seems to be no ratio of occurrence or quantitative relation of one to the other, but zinc is present in larger amounts than copper.

Sample No. 620–a–4 was composed of the soft parts of a number of fresh-water mussels taken from the Millstone River east of Princeton, at a point where all the water of the river is collected from a low, level, sandy area far removed from any possible metallic veins. It is interesting to note that this fresh-water form collects both copper and zinc from such a natural water and in about the same amounts as do the salt-water organisms. This may be true of other fresh-water forms, but as yet this sample of *Unio* is the only one analyzed. Iron and manganese in this case were not determined, as it was difficult to completely eliminate the silt contained in the intestines, and as this silt would contain both iron and manganese, their determination under the circumstances would be of no interest.

In the note "A possible source of vanadium in sedimentary rocks"[1] it was stated that the conditions for the fixation of these small quantities of metal in the mud and slime at the bottom of the shallows and lagoons are ideal, about the Tortugas at least, as the constant liberation of hydrogen sulphide by the mud in the slightly alkaline sea-water would precipitate all four of the above metals as sulphides, even though they were present in very small quantities.

To test this, the sample No. 615–A–1 was analyzed for these metals. The sample consists of a mud collected in the shallow lagoon of the Marquesas, Florida, and taken by means of a special sampling apparatus at a depth of 2 feet below the surface of the mud. The results of this analysis are shown in the table. It is not surprising to find iron and manganese, but zinc and copper are both present and in larger quantities than the analyses show them to be present in the organisms; therefore these metals are concentrated in this bottom mud. Unfortunately, no other samples of muds were taken and the extent of concentration of copper and zinc can not be determined at present.

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[1] Amer. Jour. Sci., vol. XLVI, p. 471.

Copper has been reported as a component of the surface mud of the ocean bottom at other localities, and both zinc and copper have been reported as being present in small amounts in many limestones and dolomites.

The calcareous mud of the Marquesas is limestone in the making, and when the conditions under which it accumulates are considered there can be very little doubt that the copper and zinc content is derived from organisms which have concentrated these metals from sea-water, and at death the metal content of their decaying tissues is fixed as sulphides and becomes a part of the limestone or sedimentary rock thus formed.

Even though the percentage (0.016 per cent for copper and 0.009 per cent for zinc) is seemingly small, the actual weight of metal present when calculated for large areas of limestone is considerable, as each cubic meter of rock would contain 432 grams of copper and 243 grams of zinc—an amount quite sufficient to produce metallic deposits of commercial value after secondary concentration by natural agents.

VI.

THE TRACKING INSTINCT IN A TORTUGAS ANT.

By ALFRED GOLDSBOROUGH MAYOR

THE TRACKING INSTINCT IN A TORTUGAS ANT.

By Alfred Goldsborough Mayor.

In the preparation of this paper it is a pleasure to acknowledge my indebtedness to Professor William M. Wheeler for his identification of the ant in question and for references to the literature. All papers previous to 1910 are referred to in Wheeler's masterly work "Ants," published by the Columbia University Press, while the studies of later authors, such as Pieron, Turner, Santschi, etc., are referred to by R. Brun (1914, Rie Raumorientierung der Ameisen und das Orientierungs problem in allgemeinen, 234 pp., 51 fig. Jena). Another important paper is by V. Cornetz (Les exploration et les voyages des fourmis, 192 pp., 83 fig. Paris, 1914). In this brief paper we will not attempt to review the already voluminous literature, but refer to it only as it relates to our observations.

Monomorium destructor Jerdon, a tropicopolitan ant of East Indian origin, was identified in Florida by Wheeler (1906, Entomological News, vol. 17, p. 265). It is a small, reddish-brown ant, and is a great pest in the wooden buildings of the Tortugas laboratory, making its nests in crevices of the woodwork. So voracious are these insects that we are obliged to swing our beds from the rafters and to paint the ropes with a solution of corrosive sublimate, while all tables must have tape soaked in corrosive sublimate wrapped around their legs if ants are to be excluded from them. These pests have the habit of biting out small pieces of skin, and I have seen them kill within 24 hours rats which were confined in cages.

The experiments herein described were made on the flat wooden floor of the laboratory, this flatness having possibly prevented the ants from orienting themselves with respect to conspicuous objects or unevenness in the ground, although I have no evidence that they do this under any conditions.

In order to attract the ants, a number of recently killed house-flies were impaled upon a pin; and then, upon looking over the floor, one soon found an ant wandering in a tortuous course over the flat surface. The pin with its lure of flies was then thrust into the floor in front of this foraging ant, which would often pass within 0.25 inch of the lure without perceiving the flies; but if its course were such that it came appreciably nearer than 0.25 inch, the ant suddenly turned toward the flies, and without apparent excitement appeared to "inspect" them, spending a half minute or more crawling over them and stroking them with its antennæ. This applies to

dead flies, for if a fly be wounded and moving the ant usually becomes much excited and proceeds to bite it, and it is remarkable how efficacious the bites are in quieting the fly. In any event this "finder ant" soon leaves the flies without carrying off any piece of them, but instead of moving off in the erratic and tortuous path it was pursuing before it found the flies, it now goes in a fairly *straight* path toward some crevice in the floor, out of which there soon pours an excited swarm of its nest-mates, who proceed toward the flies in a fairly straight path, but which is not necessarily identical with that taken by the "finder ant" in returning from the flies to the nest. Often the path of the return swarm is not quite right in direction, and thus the ants would pass to one side or the other of the flies; but, curiously, when the right distance has been made and the ants are about to pass the flies, the swarm suddenly breaks up into individuals coursing in random fashion in all directions (the "Turner's curves" of authors). It is very dramatic to see the straight path of the once orderly file of ants suddenly break into this random wandering, but so accurately do they gage the distance that I have never seen them miss it by more than 2 inches in a journey of 8 feet, while often the direction may be so much in error that in going 8 feet the ants may tend to pass as much as 4 inches to one side or the other of the flies. Of course, in cases when the path of the main swarm does not happen to "strike" the flies, but passes to one side and then breaks up, many of the ants will not succeed in finding the flies, but must wander in erratic curves over the floor. A considerable number, however, do find the flies, and within a few minutes a fairly straight swarm-path is established between the nest and the flies.

Cornetz, observing ants in Algiers, finds that when an ant returns to the nest it pursues a fairly straight path which is more or less right in direction, but in any event, when the ant has gone the correct *distance*, it begins to wander in more or less tortuous courses until it finds the nest.

EXPERIMENTS.

In studying the behavior of the Tortugas ants I would usually place a few recently killed house-flies upon the floor in order to draw out the ants, so that many of them would be constantly moving over the floor in all directions and the entrance to the nest would be well defined by crowds of moving ants in its neighborhood. Often paper was pinned down to the floor in order that the paths of the ants might be drawn accurately in pencil.

I. When an ant has discovered a dead fly and is engaged in "inspecting" it, we may draw a circular line of a solution of corrosive sublimate in 35 per cent alcohol about a foot in diameter

around the fly. Then, when the ant leaves the fly and proceeds more or less in the direction of the nest, it soon meets with the barrier of corrosive sublimate. This arrests it. It then crawls around close to the inner edge of the barrier, then suddenly goes straight back to the dead fly, and again starts out for the nest, to be again arrested by the barrier of corrosive sublimate. Finally, after repeating these movements a number of times, it crosses the barrier and goes in a more or less direct path toward the nest; but when it meets other ants and rubs antennæ with them they are not excited and no swarm comes back to the dead fly. The fact that the "finder ant" has crossed the corrosive sublimate seems to have destroyed its power to excite other ants or to draw them back to the lure it has found.

II. Conversely, if after a "finder ant" has gone back to the nest, and the swarm is well established and the fly is being torn to pieces, a circle of corrosive sublimate be drawn around the fly, the ants coming from the nest are at once arrested when they reach the outside of the ring of poison. A block occurs and in about a minute nearly every ant between the outside of the ring and the nest is seen to be returning straight to the nest, so that the swarm vanishes in a short time. The ants caught *within* the ring usually show some hesitation in crossing the poisoned area, and once having crossed, they rarely return to the fly, so that the numbers attacking the fly constantly decrease, due to lack of new recruits.

III. On one occasion an ant which was carrying a grain of sand in its mandibles found a dead fly and "inspected" it in the usual fashion, but did not drop the grain of sand. It then crawled off toward the nest, carrying the sand, but no return swarm came. No inferences can be drawn from this observation, however, for it is based on only a single case, although it seems possible that under certain conditions a "finder ant" does not produce a return swarm.

IV. If after having found the fly the "finder ant" is allowed to go toward the nest and to rub antennæ with several of its nestmates, and is then gently brushed up from the floor with a camel's-hair brush and removed, the ants it has encountered show normal excitement; and this excitement *spreads* by contact to others in their neighborhood, but no return swarm occurs. The excited ants rushing to and fro often cross the path the "finder ant" traversed in going from the fly toward the nest, but none of them attempts to follow the trail back to the fly.

V. If the "finder ant," after having "inspected" the fly and started toward the nest, is brushed up and carried through the air to the nest-crevice, the ants it falls among may at times display some excitement, but of this I am uncertain. Certainly, however, no return swarm comes back to the fly. Apparently, having been

carried through the air, the "finder ant" becomes incapable of conducting a return swarm to the fly. Indeed, it appears probable that the "finder ant" has lost its sense of orientation, for if we brush up an ant from the midst of the crowd moving in the neighborhood of the nest-crevice and carry it through the air to a dead fly, say 8 or 10 feet away, the ant "inspects" the fly in a normal manner, but instead of starting on a fairly straight path back to the nest-crevice, it courses widely over the floor in all directions, every now and then turning and going *straight back* to the fly, and then starting out again. If in the course of these wanderings it meets with several of its fellows and rubs antennæ with them, it then returns to the fly, while its mates follow it in much excitement and a swarm starts; but apparently the "finder ant" has *lost* its sense of the direction of the nest after having been carried through the air.

But while this may apply to *Monomorium destructor*, it seems not to be true for certain other ants. Thus, Brun found that *Formica rufa* and several other species of ants have a remarkable sense of direction which it is difficult to confuse. This sense, according to Brun, is complex and composed of perceptions which are chemical, topographical, tactile, gravitational, and (as Santschi showed) a perception of the direction of light. They seem also to be able to remember the "lay of the land," even after an interval of 3 weeks between visits to a given region. It is possible that the flat floor of the laboratory at Tortugas presented no topographical features of sufficient definiteness to serve as guides to the ants, who became lost, much as a good woodsman might be lost at sea. It is also possible that different species of ants differ widely in their sense of orientation, and that in *Monomorium destructor* this sense is somewhat poorly developed.

VI. If the abdomen of an ant be slightly notched or split with a pair of fine dissecting scissors, so as to mark the ant, she does not seem to be rendered abnormal in behavior by the operation, although such ants are apt to die after a few hours, apparently through injury to the tracheal system. If such an ant finds a dead fly it "inspects" it in the normal fashion, and then starts off normally, but the other ants pay no attention to it and are not excited if it rubs antennæ with them. At times, indeed, the normal ants may interfere with the maimed ant, seizing it by the legs, so as to arrest its progress, but generally they wholly ignore its presence. In any event, when the marked "finder ant" has met several of her nest-mates and rubbed antennæ with them, she starts back in a *straight course* to the fly, but none of the nest-mates follow it, and thus no swarm occurs. In one experiment such a maimed "finder ant" repeated this return journey eight times, each time after having rubbed antennæ with its nest-mates, but none of them followed her back

to the fly. It seems that her instinctive behavior as a "finder ant" is unimpaired by her injury, but due to this injury her nest-mates no longer recognize her.

VII. It is difficult to *prove* that the "finder ant" actually conducts a swarm of her nest-mates back to the lure she has found, and I tried many experiments to demonstrate or refute this hypothesis. Most of these were unsuccessful, due to the "finder ant" becoming indistinguishable from the numerous ants crowding around her. Several instances, however, seem to give a positive result, leading me to infer that the "finder ant" actually takes the lead and *conducts* the swarm back to the dead fly. These successful experiments were made with unusually small ants, so small that they can be distinguished even among a crowd of their nest-mates, unless, indeed, another equally small individual enters the swarm. These small ants are only about half the size of the average worker. Moreover, workers of normal size are much more numerous, outnumbering these small ants perhaps 50 to 1. These small ants appear to be normal in behavior, for if one of them finds a dead fly it goes through with the usual "inspection," and then starts off deliberately more or less in the direction of the nest. When it meets a cluster of its nest-mates it rubs antennæ with them, and this causes intense excitement, which spreads rapidly by contact from ant to ant. As soon as this is accomplished, the small ant starts back toward the fly in a fairly straight course, but which is rarely or never *identical* with the path she took from the fly to her mates. The nest-mates crowd around the "finder ant," and others follow these, so that a moving file of ants is seen rushing toward the fly as if an army were moving along its length with the small "finder ant" in the lead. Of course, if other dwarfed workers were seen in this army the observation was thrown out as non-convincing; but in several instances I clearly saw one of these dwarfed ants *lead* a small swarm, composed entirely of its larger nest-mates, back to the dead fly, and am thus inclined to think that it is the normal function of a "finder ant" to "personally conduct" her nest-mates back to the food she has discovered.

VII.

A COLLECTION OF FISHES FROM SAMOA.

BY

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Two figures.

A COLLECTION OF FISHES FROM SAMOA.

By Henry W. Fowler and Charles F. Silvester.

The specimens forming the basis of the present paper were collected at Pago Pago in the spring of 1917 by the Carnegie expedition to Samoa. Efforts were made chiefly to secure small or inconspicuous forms, and, though the collection embraces only 53 species, several are rare and one species is described as new. The collection consists of five lots of small fishes taken from the following localities. First lot, April 5, 1917, from the cove just south of Aua village and 100 feet northwest of Dr. Mayor's "Aua line." These were taken by lifting bunches of coral from the bottom and then breaking the coral. The second lot has the same data, except a few specimens screened at the bottom with wire and mosquito screening. The third lot, taken April 6, consists of specimens shaken from coral in the reef in front of the hospital, Pago Pago Harbor, Tutuila. The fourth lot was obtained March 20, 1917, from tide-pools near Double Point, just west of the entrance to Pago Pago Harbor. The fifth lot is simply labeled Pago Pago.

The collection is now contained in the Museum of the Academy of Natural Sciences, Philadelphia.

The ichthyology of Samoa has claimed the attention of several investigators. The most important general account is the "Fische der Südsee" by Günther.[1] This was founded largely on the colored drawings of fishes from various Polynesian Islands made by Andrew Garrett. After the first few parts were published the work was discontinued for a number of years, though in 1910 it was finally completed. Previously some of the fishes collected by the Godeffroy firm, which also financed Günther's "Fische der Südsee," were sent to the Vienna Museum and described by Kner and Steindachner.[2] Later a collection from Savaii and Upolu was made by Rev. S. J. Whitmee and sent to the British Museum. The percoids from this collection are published in Boulenger's Catalogue.[3] Streets made a small collection about 1876, which he later described.[4] In 1900 Fowler[5] reported a small collection made at Apia, Upolu, by Dr.

[1] Jour. Mus. Godeffroy, I (Heft I), 1873, pp. 1–24, pls. 1–20; II-III (Heft V-VI), 1874, pp. 25–96, pls. 21–60; IV, 1875, pp. 96–128, pls. 61–83; V (Heft XI), 1876, pp. 129–169, pls. 84–100; VI (Heft XI), 1877, pp. 169–216, pls. 101–120; VII (Heft XV), 1881, pp. 217–256, pls. 121–140; VIII (Heft XVI), 1909, pp. 261–388, pls. 141–160; IX (Heft XVII), 1910, pp. 389–519, pls. 161–180.

[2] Sits. Ak. Wiss. Wien, 54, 1866, pp. 356–395, 5 pls.; *l. c.*, 58, 1868, pp. 26–31, 293–356, 9 pls.

[3] Cat. Fish. Brit. Mus., I, ed. 2, 1895, pp. 1–394, pls. I-XV.

[4] Bull. U. S. Nat. Mus., VII, 1878, pp. 43–102.

[5] Proc. Acad. Nat. Sci. Phila., 1900, pp. 524–528.

H. C. Caldwell, of the U. S. Navy, and received at the Academy of Natural Sciences of Philadelphia in 1857. The most complete work appeared as "The Fishes of Samoa," by Jordan and Seale,[1] though its scope is widened to include a list of all the species then known from Oceania. Finally Steindachner,[2] under the title "Zur Fischfauna der Samoa-Inseln," reports a collection made by Dr. Rechinger in 1905.

OPHICHTHYIDÆ.

Chlevastes colubrinus (Boddaert).

One example, 683 mm. Aua Reef, Pago Pago Harbor, June 14, 1920. Head 8.4 to vent. When fresh in alcohol grayish white generally, lower surface of tail slightly tinted with pale cream-color. Blackish-brown cross-bands broad, nearly or quite half width of pale interspaces, most all complete, little narrower below, and about edges of each narrow whitish border. Beginning at vent, 10 interspaces with rounded, black blotch within each along fin edge. Also along side large, round, black blotch in each of interspaces, of which several may be dorsal, or some absent and extend for some extent as small blotches.

Chlevastes fasciatus (Ahl).

One example, 549 mm. Same locality as preceding. Head 8.87 to vent. Differs in dark cross-bands, much narrower, at least much less than one-third width of pale interspaces. Also, all along dorsal surface of trunk pale interspaces, each with small, round blackish blotch but little larger than eye. These extend only on first four interspaces of tail. All dark cross-bands interrupted below, except last three on tail and no dark blotches on anal, which uniform whitish, except last three dark cross-bands.

MURÆNIDÆ.

Gymnothorax punctatus (Schneider).

Head about 8; depth at vent about 19; head width about 3.66 in its length; snout 5.5; mouth 3.5; interorbital 5.5; eye 2 in snout. Body moderately long, well compressed, rather slender with convexly flattened sides; tail long, slender, and tapers largely from vent. Combined head and trunk about 1.75 in rest of body.

Head rather small, compressed, with slightly swollen pharynx, apparently rather blunt in front. Snout (damaged above) apparently conic and about as broad as long. Eye rounded, little backward in mouth length, without eyelid. Mouth rather small, horizontal. Teeth uniserial in jaws, entire, compressed, attenuate. First 7 teeth each side in front above little larger than others. Vomer in front with 2 similar teeth, front one smaller. No tongue. Row of very small and rather wide-set cutaneous points, minute, along lower lip. Upper lip (damaged) not examined. Jaws apparently equal,[3] lower jaw with low rami, convex and strong. Front nostril in short, fleshy tube near snout tip. Interorbital convex. Occipital region well swollen or convex.

Gill-opening, little below median body axis, little inclined from horizontal, length about equals snout. Pharynx smooth.

Skin smooth, tough, rather thick. Along each side of mandible 5 pores. Lateral line obscure, with row of indistinct rather wide-set pores along side medially.

Dorsal origin apparently about last third in space between posterior edge of eye and front of gill-opening, fin high, especially on last half of tail, and narrowly contin-

[1] Bull. Bur. Fisheries. U. S., XXV, 1905 (Dec. 15, 1906), pp. 173–455, pls. 33–53.

[2] Sits. Ak. Wiss. Wien, CXV (1), 1906, pp. 1369–1425.

[3] This specimen has the head slightly damaged and due allowance should be made in these proportions.

uous with very small obsolete caudal to anal. Caudal length less than eye. Anal less than half high as dorsal. Vent directly in front of anal origin.

Color in alcohol very pale grayish white generally, everywhere marked with small, pale brownish, irregularly crowded dots or specks of variable size and density. Spots pale or obsolete along fin borders, but distinct on basal portions of fins. Under surface of head and belly pale, nearly immaculate. Gill-openings very inconspicuous, pale, same as general color. Iris slaty. Teeth whitish.

Length about 173 mm.

Only the above example from Pago Pago. Probably pale yellowish generally in life, with dark specks.

Gymnothorax goldsboroughi Jordan and Evermann, a synonym of the above species, differs from our example in coloration, as it is marked with very many minute whitish or pale spots and has a distinct white fin edge, not seen in our specimen.

Gymnothorax pictus (Ahl).

Head about 7.75; depth at vent about 15.4; head width 2.4 in its length; head depth 2; snout 6; eye 8; mouth 2.8; interorbital 6.

Body moderately long, well compressed, moderately deep, and with convexly flattened sides, long tail tapering largely behind. Combined head and trunk length equals rest of body.

Head moderate, compressed, pharynx scarcely swollen, flattened sides but slightly approximate below, front rather robust and upper profile little concave over eye. Snout conic, tip and surface convex, length seven-eighths its width. Eye rounded, little nearer upper profile than mouth, about midway in gape of latter, without eyelid. Mouth moderate, horizontal, closing completely. Lips rather tough, fleshy, and row of minute papillæ or filaments around edge of each. Teeth conic, entire, uniserial along jaw edges. Front teeth in each jaw enlarged as patch of several (6 to 8), strong, erect. Single row of small, erect conic teeth down vomer. No tongue. Upper jaw slightly protrudes. Mandible rather low, strong, surface convex. Front nostril in short, fleshy tube about half of eye. Posterior nostril simple pore nearly over middle of eye within interorbital space. Interorbital convex. Occipital region well swollen convexly.

Gill-opening near median body axis, slightly inclined from horizontal, about 0.66 of eye. Pharynx smooth.

Skin smooth, tough, of about uniform texture. Along each upper lip at least 6 distinct pores well above edge, first slightly in front of nasal tube. Pore directly above upper anterior eye edge in front of posterior nostril. Pair of pores little above bases of front nasal tubes, and another pair well up about midway in snout length. Four distinct pores along each mandibular ramus, well below edge of lip. Lateral line not developed.

Dorsal origin about midway between posterior eye edge and front of gill-opening, fin moderately high, though more elevated posteriorly, where confluent with small caudal. Caudal rounded, about long as eye. Anal similar to dorsal, though much lower. Vent about an eye diameter in front of anal origin.

Color in alcohol, olive-brownish generally, washed with pale lilac-gray, producing a more or less uniform tint. Though visible to the naked eye as very fine reticulations or specks, under a lens body seen to be everywhere marked with dusky to blackish-brown vermiculations, extremely minute, though well defined. End of tail and muzzle tinged slightly more brownish. No dusky blotch at gill-opening, or at mouth corner; latter pale inside. Iris dull slaty. Teeth pale.

One 115 mm. long, from Pago Pago. It differs from any example of the species we have seen in its very minute, dark vermiculations. Among the many figures of Bleeker is none of the small size of our own example or with its color pattern.

Anarchias allardicei (Jordan and Seale).

Head 6.87; depth at vent about 15.25; head width 3.16 in its length; head depth 2.87; snout 5.75; eye about 9; mouth 3.12; interorbital 5.75.

Body moderately short, well compressed, rather deep, with convexly flattened sides and tail tapering rather abruptly behind. Combined head and trunk 1.2 in rest of body.

Head moderate, compressed, depth slender and pharynx not swollen, about even in width, convex above and below. Muzzle rather obtuse, upper profile slightly concave over eye. Snout obtuse, convex at tip and on dorsal surface, length three-fourths its width. Eye rounded, about median in depth over mouth, little backward in gape length, without eyelids. Mouth rather small, horizontal, completely closes. Lips rather tough, fleshy, entire along edges. Teeth conic, entire, subequal, strong. Upper teeth with one series small, mostly uniform and erect all around outer edge of jaw and inner series of enlarged, depressible, wide-set sharp-pointed teeth on both sides. Lower jaw with similar dentition. Front of vomer with two large fangs and row of few small teeth down its shaft behind. No tongue. Upper jaw tip slightly protrudes, and mandible with strong rami. Anterior nostril short, fleshy tube about as long as pupil, near snout tip. Posterior nostril simple pore over eye center within interorbital space, which is convex. Occipital region not especially swollen, convex.

Gill-opening close to ventral profile, as simple pore, size of posterior nostril. Pharynx smooth.

Skin smooth, tough, 5 pores along each side of upper lip, first in front of anterior nostril, second close behind base of anterior nostril, third nearer eye than second, fourth below front pupil edge, and fifth close behind eye. Pair of pores above, close to and within front internasal space, second pair midway on snout above, third pair adjoin hind nostrils over eyes. Lower edge of mandible with 5 pores each side, gradually more distant from one another backward. No lateral line.

Dorsal begins as very slight ridge over gill-opening; extends back also as very slight fold to caudal, where it is a little broader. Caudal rounded, about as long as eye. Anal developed only as low fold on under surface of tail about last two-elevenths of its length, continuous also with caudal.

Color in alcohol uniform dusky brown above. Under surface of head, belly, and end of tail tinted brownish; hind edge of latter whitish. Iris pale slaty.

One example, 116 mm. long, from Pago Pago.

Varies from the original account in the presence of two large anterior vomerine teeth, and no smaller posterior vomerine teeth are mentioned by its describers. The figure of *A. allardicei* shows the dorsal origin beginning apparently nearer the mouth corner than the gill-opening, while in our example it begins over the gill-opening. *A. allardicei* has been united[1] with *A. knighti* Jordan and Seale, but its mottled coloration and more elevated dorsal doubtless renders it distinct.

HEMIRAMPHIDÆ.

Hyporhamphus pacificus (Steindachner).

Head from upper jaw tip 4.6; depth 9.33; D. III, 14; A. III, 16; P. I, 10; V. I, 5; scales 66 in lateral series from shoulder to caudal base and 6 more on latter; about 7 scales above lateral line to dorsal origin; 2 scales above anal origin to lateral line; snout about 2.66 in head without beak; eye 3.33; maxillary 4.5; interorbital 4.33; pectoral 2.25; first branched dorsal ray 2.87; first branched anal ray 3.5; least depth of caudal peduncle 5.25; lower caudal lobe 1.25; ventral 3.2.

Body elongate, rather robust, slightly compressed, though sides are convex and not flattened, deepest medially. Caudal peduncle compressed, least depth half its length.

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[1] Günther, in Jour. Mus. Godeffroy, XVII, 1910, p. 421.

Head compressed, flattened sides approximated below where width is half that of cranium, well attenuated forward. Snout long, depressed, width 1.75 in its length. Eye elongately ellipsoid, close to upper profile, slightly advanced in head (without beak). Free portion of upper jaw nearly an equilateral triangle as seen from above, its length 2.4 in snout. Maxillary 1.5 to eye, broadly vertical, width equals pupil. Lower jaw long, slender, so rest of head from upper jaw tip only 0.75 of remainder of beak. Teeth fine, simple, in narrow bands in jaws. Upper buccal fold narrow, lower broader. Tongue elongate, depressed, smooth, free. Nostrils rather large, together, their depression as long as pupil along upper snout edge close before eye. Interorbital depressed to very slightly concave. Opercle broad, smooth, width 1.25 eye diameters. Preorbital slightly less than eye.

Gill-opening forward to front eye edge. Rakers 10+23, lanceolate, 1.5 in gill-filaments and latter 1.75 in eye. Isthmus narrowed, trenchant frenum in front.

Scales deciduous, all well imbricated and above computations, largely according to pockets. Dorsal and anal mostly covered with small scales, at least basally, also caudal base. Scales with basal circuli 19. Lateral line complete, apparently low along side, touches at ventral origin, tubes simple and each well exposed.

Dorsal origin well posterior, much nearer caudal base than ventral origin or little behind last third in space between caudal base and pectoral origin, anterior rays longest, though their tips extend only to middle of fin when depressed, and entire depressed fin three-fourths to caudal base. Anal inserted opposite dorsal, similar. Caudal well forked, lower lobe much longer than upper (damaged). Pectoral base high, fin 4 to ventral origin, latter midway between pectoral origin and caudal base, fin short or but 2.25 to anal. Vent close before anal.

Color in alcohol brownish on back, paler on under side, apparently whitish in life. Down middle of back well-marked dusky line with narrow one each side and parallel, also scale edges same tint. From shoulder, narrow silvery-white band to caudal base, widest below dorsal, where about two-thirds vertical eye diameter, and its upper border tinted slaty narrowly or with deeper line. Fins all pale brownish, vertical ones and pectoral above tinted little with grayish. Iris silvery white, also side of head. Inside gill-opening marked with dusky dots.

One 205 mm. long, from Pago Pago. Agreement was found with Hawaiian examples, which have rakers 9+22.

Hyporhamphus samoensis Steindachner,[1] as suggested by Günther, is probably the same. This species is doubtless identical with *Hemiramphus dussumieri* Valenciennes.

MUGILIDÆ.

Neomyxus chaptali (Eydoux and Souleyet).

Head 3.4; depth 3.4 to 3.5; D. IV–I, 9; A. III, 9; scales 37 to 39 in median lateral row to caudal base and 5 more on latter; 12 or 13 scales transversely between dorsal and anal origins; about 21 or 22 predorsal scales; snout 3.5 in head; eye 3.25 to 3.33 in head; mouth width 2.87; interorbital 2 to 2.4.

Body compressed. Head broad above, constricted below, upper profile nearly straight. Snout broadly obtuse as seen dorsally, length two-fifths its width. Eye large, posterior edge midway in length of head, rim free. Premaxillaries concealed. Upper front lip thick, width slightly over half of eye. Edges of lips with single row of rather large fleshy papillæ. Mandible included in upper jaw. Nostrils small, close, near upper edge of snout. Interorbital broadly convex, with slight depression in front. Rakers 22+36, slender, lanceolate, little less than filaments, the latter 1.66 in eye. Scales large, firm, in even longitudinal rows; basal radiating striæ 4 to 6, with 3 to 5 incomplete accessory ones; circuli rather coarse. Dorsal, anal, and caudal largely

[1] Sits. Ak. Wiss. Wien, CXV (1), 1906, p. 1418, Upolu.

covered with small scales. Spinous dorsal origin about opposite pectoral tip. Soft dorsal inserted little behind anal origin. Second anal spine but little shorter than third. Pectoral reaches half-way to anal. Ventral inserted about opposite middle of depressed pectoral. Vent close before anal.

Color in alcohol brownish on back, sides and below silvery white. Dorsals and caudal tinted with dusky, also pectoral, the latter with small dark spot at origin. Iris whitish.

Length 73 mm. (caudal damaged). Two small examples from Pago Pago.

HOLOCENTRIDÆ.

Holotrachys lima (Valenciennes).

One example, 68 mm. long.

Holocentrus punctatissimus Cuvier.

Head 2.6 to 2.75; depth 2.66 to 2.8; D. XI, 14 or 15; A. IV, 9 or 10; scales in latera; line 35 or 36 to caudal base and 2 more on latter; 4 scales above lateral line to soft dorsal origin; 7 scales below lateral line to spinous anal origin; 7 predorsal scales snout 3.8 to 4.2 in head; eye 2.66 to 2.75; maxillary 2.75 to 2.66; interorbital 4.12 to 4.2. Head about half as long as wide. Snout length two-thirds its width. Posterior edge of pupil about midway in head length. Jaws about even. Maxillary two-fifths in eye, expansion 2.75. Bands of villiform teeth in jaws, on vomer and palatines. Interorbital level. Cranial bones striate. Preopercle spine long, strong, reaches back slightly beyond gill-opening, length two-fifths of eye. Preorbital narrow, with several strong marginal spines. Suborbital chain about equally wide as preorbital, its serrated edge finer. Edges of suprascapula, preopercle, opercle, and subopercle serrate. Preopercle ridge entire. Rakers II 2+8 III, lanceolate, nearly long as filaments, which one-third of eye. Scales largest on flanks, smaller on predorsal and vertical fin bases. Cheek with 4 rows of scales. Scales with basal parallel vertical striæ 18 to 25 (more numerous in larger examples); 7 to 13 strong, broad apical spines.

Color when fresh in alcohol pale orange, generally as ground-color. Back with two and a half longitudinal rows of dusky brown, narrow, and not sharply defined, parallel with lateral line above. Below lateral line six and a half broad longitudinal rows of similar color, lower much narrower. Head brownish above, tinged with pale orange below, and each scale on cheek and opercles with pale dusky spot. Spinous dorsal grayish, with first three and last membranes jet black. Other fins all pale orange to whitish. Iris silvery, fading slaty.

Four examples, all young, shaken from coral from reef in front of hospital, Pago Pago Harbor, 42 to 45 mm. long. Also 3 examples 64 to 71 mm. long, from tide-pools near Double Point, just west of the entrance to Pago Pago Harbor. These largely in agreement with Günther's figure.[1]

Two small examples from cove just south of Aua village. These have a conspicuous dark blotch in the front of the spinous dorsal.

Holocentrus diadema Lacépède.

Head 2.87; depth 3.33; D. XI, I, 12, I; A. IV, 9; scales 50 in lateral line to caudal base and 3 more on latter; 5 scales above lateral line to origin of soft dorsal; 9 scales below lateral line to origin of spinous anal; 9 predorsal scales; snout 4.25 in head measured from upper jaw tip; eye 3; maxillary 2.87; interorbital 4.25. Width of head half its length. Length of snout four-fifths its width. Eye with posterior edge of pupil midway in head-length. Closed lower jaw slightly projects. Maxillary reaches beyond anterior edges of eye, not quite to pupil, expansion about one-third in eye. Bands of villiform teeth in jaws, on vomer and palatines. Interorbital level. Cranial

[1] Proc. Zool. Soc. London, 1871, p. 660, pl. 60, 2 figs.

bones striate. Preopercle spine reaches back only to bony edge of infraopercle. Preorbital very narrow, and suborbital chain but little wider, its edge more weakly serrate than finely serrated preorbital edge. Rakers II 2+9 III, lanceolate, about three-fourths of filaments, which one-third of eye. Scales largest on flanks, smaller on predorsal and breast. Cheek with 5 rows of scales. Scales with parallel vertical striæ 60 to 70 basally; 8 blunt, short basal denticles; 16 to 18 broad, strong apical spines.

Color when fresh in alcohol bright rosy-red generally, with 3 rows of narrow, dark longitudinal bands above the lateral line and 5 broad ones below. Later these faded out below and made up of brownish dots, as seen under a lens. Upper surface of head washed with pale brownish. Iris silvery, fading slaty. Spinous dorsal pale rosy generally, fading whitish, except large median black blotch on first two membranes, then black blotch submarginally after each dorsal spine, and from fourth spine basally black band back to last spine. Other fins all uniform pale rosy, fading whitish.

One example, 78 mm. long, from coral in reef in front of the hospital, Pago Pago Harbor. It differs from examples in the Academy of Natural Sciences of Philadelphia in the much shorter preopercular spine and the coloration. It has more whitish on the spinous dorsal, lacks entirely the blackish on the front part of the ventrals and anal, besides having a pale or whitish pectoral axil.

Holocentrus praslin Lacépède.

Small examples from tide-pools near Double Point, just west of entrance to Pago Pago Harbor.

Holocentrus sammara (Forskål).

One example from Pago Pago, 100 mm. long. It agrees with Bleeker's figure in the anterior dark blotch on spinous dorsal median and lengthwise. Jordan and Seale[1] describe four examples from Samoa. First has "spinous dorsal broadly edged with blood red." Second has "dorsal maroon, whitish spots at base, tips white, and front of fin with large, black, red-washed blotch." Third with "large black blotch on front of spinous dorsal." Fourth with "front of soft dorsal with very large blotch of maroon-black, fin otherwise flesh-color, tips white." In a Hawaiian example Jordan and Evermann show lengthwise lines made up of dark spots.

Also 3 small examples from cove just south of Aua village, April 5, 1917. In two of these the front of the spinous dorsal has a large black blotch and succeeding membrane with less distinct dark blotches. Remaining example with spinous dorsal uniformly pale or whitish.

CHEILODIPTERIDÆ.

Amia savayensis (Günther).

Five from reef in front of hospital, Pago Pago Harbor. Fourteen from cove just south of Aua village. These agree in every way with the large series of Philippine examples in the Philadelphia Academy.

Amia novemfasciata Cuvier.

Adult and young example from tide pools near Double Point, just west of entrance to Pago Pago Harbor, March 20, 1917. Two also from Pago Pago.

Fowleria marmorata (Alleyne and Macleay).

Head 2.5; depth 3; D. VIII–I, 9; A. II, 9; scales 23 in lateral line to caudal base and 2 more on latter; 2 scales above lateral line, 6 below; 8 predorsal scales; snout 4.16 in head; eye 3.87; maxillary 2; interorbital 5.5.

Body elongate, compressed, deepest at spinous dorsal origin, profiles alike. Caudal peduncle compressed, least depth 1.12 its length. Head large, compressed, profiles

[1] Bull. Bureau of Fisheries, XXV, 1905, p. 227.

alike. Snout convex on dorsal surface, slightly so in profile, length about three-fifths its width. Eye large, impinging on upper profile, posterior edge about midway in head length. Mouth large, well inclined, lower jaw slightly included. Maxillary extends beyond posterior edge of pupil, not quite to posterior edge of eye, expansion little less than pupil. Villiform bands of teeth in jaws and on vomer, none on palatines. Tongue elongated, rounded tip free. Nostrils together, directly in front of eye. Interorbital level. Preopercle edge entire. Rakers 1+6 short points, about equal to filaments, which one-third of eye. Scales large, little smaller along body edges, and 2 rows on cheek. Basal radiating striæ 13 or 14; apical denticles 80 to 90; circuli fine. Lateral line of 5 well-exposed, simple tubes first, then only as row of pores to caudal base, one in center of each scale exposure, and all concurrent largely with dorsal profile. Third dorsal spine longest, reaches back to soft dorsal origin. Soft dorsal and anal alike, opposite, rather elongate, height of former slightly less than half of head. Caudal rounded. Pectoral reaches anal origin, ventral little shorter.

Color in alcohol deep brick-brown, with 9 vertical cross-bars, twice width of pale interspaces. Head mottled brownish, with pale lilac tint on mandible and branchiostegal region. Large jet-black, round blotch, little less than eye, though larger than pupil and margined narrowly with golden-brown. Small, black crescent above opercular spot. Pale bar from eye to preopercle angle, lower edge dusky. Each scale on caudal peduncle with median dusky blotch, rather small, though distinct. Two rows of scales between pectoral and ventral bases on side of abdomen, with slightly oblique, narrow dusky line. Fins all dusky-red. Iris brownish.

Length 47 mm.

Also smaller examples same locality. Head 2.5; depth 2.87; D. VII–I, 9; A. II, 8; scales about 21 in lateral line to caudal base and 2 more on latter; snout 3.75 in head; eye 3.33; maxillary 1.8; interorbital 4; length 33 mm. This approaches *Apogonichthys isostigma* Jordan and Seale, in the more spotted appearance, which possibly may not be distinct from *A. marmoratus* Alleyne and Macleay, as the black spots on the trunk seem to be the chief character of distinction.

Both from cove just south of Aua village, April 5, 1917.

SERRANIDÆ.

Epinephelus merra Bloch.

Two young examples from cove just south of Aua village. It differs from the adult stage in the much larger dark blotches.

Pharopteryx nigricans Rüppell.

Two small examples, from tide-pools near Double Point, just west of entrance to Pago Pago Harbor. One example from Pago Pago. All show D. XII. Length 48 to 57 mm.

Pharopteryx melas (Bleeker).

Two from cove just south of Aua village. In alcohol, body dusky-brown generally, clouded with blackish. Head same, little paler below. Iris slaty. Bases of vertical fins pale or largely whitish, all broadly blackish about outer or terminal portions. Spinous dorsal edge, together with upper soft dorsal edge, especially in front, orange. Pectoral and ventral brownish. Length 50 to 55 mm.

One 35 mm. long, same locality. All have D. XI.

OPISTHOGNATHIDÆ.

Gnathypops samoensis new species. Fig. 1.

Head 2.75; depth 3.33; D. VII, 20; A. III, 17; P. 15; V. I, 5; scales from shoulder to median caudal base about 50, and 10 more on latter; 31 tubes in lateral line; 4 scales above lateral line to soft dorsal origin; 22 scales in vertical series below lateral line to

spinous anal origin; about 40 predorsal scales; head width 1.8 its length; head depth at occiput 1.4; mandible 2.1; sixth dorsal spine 3.8; sixth dorsal ray 2.75; second anal spine 5; sixth anal ray 2.75; least depth of caudal peduncle 3; caudal 1.87; pectoral 1.6; ventral 3.12; snout 5 in head, measured from upper jaw tip; eye 5; maxillary 2; interorbital 7.5.

Body oblong, compressed, deepest at front of spinous dorsal, edges rounded convexly. Caudal peduncle well compressed, length about seven-eighths its least depth.

Head compressed, upper profile little more inclined than lower, flattened sides slightly approximated above. Snout convex over surface and in profile, short, length half its width. Eye small, advanced, posterior pupil edge near first third in head length. Mouth large, oblique, lower jaw prominent and slightly protrudes, rami robust and moderately high inside mouth. Maxillary extends back slightly beyond posterior edge of eye, though not quite halfway in head length, expansion equals eye. Lips fleshy, moderately broad. Teeth fine, pointed, in bands in jaws and on vomer and palatines. Tongue rather slender fleshy point, free and smooth. Anterior nostril in short tube near front end of snout, posterior one simple pore close to anterior edge of eye medially. Interorbital narrow, nearly level. Preorbital narrow, less than half of eye. Preopercle edge uneven, largely convex.

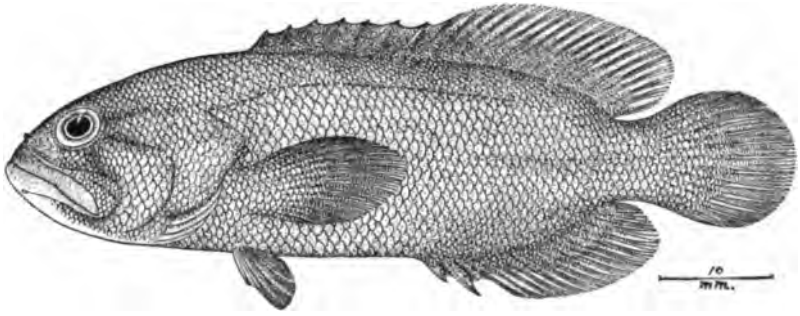

FIG. 1.—*Gnathypops samoensis* Fowler and Silvester. Type.

Gill-opening in front of posterior edge of eye. Rakers IV 1+6 III, broad, asperous knobs, longest three-fourths of filaments and latter one-third of eye. Pseudobranchiæ large as gill-filaments. Isthmus moderately broad, slightly constricted forward.

Scales moderate, smooth on front part of body, as on head, predorsal, breast, and trunk toward end of depressed pectoral, after which finely ciliated entirely. Scales on trunk in even longitudinal rows, small and crowded along edges of body, though less on breast than at most areas. Snout, front preorbital, maxillary, lips, chin, and branchiostegal region naked, head otherwise scaly. Several pores on suborbital chain close to eye, others on mandible. Fourteen scales across widest extent of cheek. Scales on opercle largest on head. Fins all with small scales basally, extending well out on dorsals and anals. Scales with basal parallel marginal striæ 11 to 13; circuli parallel laterally and same end as 4 or 5 apical denticles of small size. Lateral line only as superior branch from shoulder along back near upper profile, and not extending beyond soft dorsal. Tubes simple, large, well exposed.

Spinous dorsal inserted over origin of pectoral, spines all slender, low, pungent, graduated up to third and then about uniform. Soft dorsal inserted about midway between posterior edge of preopercle and base of caudal, fin uniformly high, rounded behind, and like soft anal posterior rays extend back to caudal base. Second anal spine longest, first little longer than third, origin much nearer origin of pectoral than base of caudal. Soft anal like soft dorsal. Caudal rounded, with median rays longest. Pectoral elongate, pointed median rays longest, reaching anal. Ventral origin slightly

in front of pectoral origin, not quite reaching halfway to anal, spine half of length of fin. Vent directly in front of anal.

Color when fresh in alcohol rich blackish-chocolate, largely uniform, with slight lilac tinge on branchiostegal region. Fins all largely blackish; also blackish blotch on opercle. Iris dark brown. Length 61 mm.

Type No. 50,563 A. N. S. P. Cove south of Aua village, 100 feet and northwest of Dr. Mayor's "Aua line." Taken by lifting bunches of coral from the bottom, April 5, 1917.

Also No. 50,564 paratype, A. N. S. P., same data: Head 2.5; depth 3; D. VII, 20; A. III, 17; scales from shoulder to median caudal base 50 and 11 more on latter; snout 5.2 in head from upper jaw tip; eye 4; maxillary 2; interorbital 7; length 55 mm.

This interesting species has no close allies and is the first occurrence of the family in Samoan waters.

(Named for Samoa.)

POMACENTRIDÆ.

Pomacentrus melanopterus Bleeker.

One from Pago Pago, 86 mm., differs from Bleeker's figure,[1] as he shows the preorbital with a spine, the suborbital rim serrate, and the posterior edge of the preopercle almost entirely serrate. The black pectoral basal blotch is shown as a dark bar within a crescent. Bleeker says,[2] however, "ossibus suborbitalibus alepidotus—non vel vix denticulatis; osse præorbitali . . . incisura plus minusve profunde ab ossibus suborbitalibus ceteris distincto, postice rotundo vel in spinullum desienta."

Pomacentrus nigricans (Lacépède).

Two young and one adult from tide-pools near Double Point, just west of entrance to Pago Pago Harbor. Apparently the same as Jordan and Seale's material, as the squamation extends much further forward than shown by Günther.[3] All our examples show a black blotch at pectoral axil and another at last dorsal ray bases.

Pomacentrus albofasciatus Schlegel.

Our material includes 4 examples from coral in the reef in front of the hospital at Pago Pago Harbor; 10 from cove just south of Aua village; 2 from tide-pools near Double Point, just west of entrance to Pago Pago Harbor.

Abudefduf cœlestinus (Cuvier).

Young example with 6 transverse dark bars, largely reflected on fins, though dorsals and anals largely and caudal completely whitish. Length 18 mm. Pago Pago.

Abudefduf glaucus (Cuvier).

Four small examples from cove just south of Aua village, and 24, all dull and uniform in color, from tide-pools near Double Point, just west of entrance to Pago Pago Harbor.

Abudefduf zonatus (Cuvier).

Seventeen from Pago Pago. No trace of the white lateral bar, though head and back are thickly spotted with pale blue. Bleeker's figure[4] does not show the blue spots as distinct and variegated as in our examples.

Glyphidodon brownriggii Günther[5] has been referred to the present species, but none of his figures show spots, and though his figure A is perhaps closer, it has the dorsals and anals broadly dark.

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[1] Atlas Ich., IX, 1877, pl. 42, fig. 6.
[2] Nat. Verh. Hollands. Maatsch. Wetensch. (Mem. Pomacent.) (3), Deel. 2, No. 6, 1877, p. 55.
[3] Jour. Mus. Godeffroy, VII (Heft. xv), 1881, pl. 124 f.y.
[4] Atlas Ich. IX, 1877, pl. 407, fig. 3.
[5] Jour. Mus. Godeffroy, VII (Heft. xv), 1881, pl. 127, figs. *a*, *c*, *e*.

Dascyllus aruanus (Linnæus).

Three small examples from cove just south of Aua village.

Chromis cæruleus (Cuvier).

Two adults from Pago Pago.

Chromis isomelas Jordan and Seale.

Head 3.16; depth 1.87; D. XII, 13; A. II, 14; P. I, 15; V. I, 5; tubes 14 in upper arch of lateral line and 7 porous scales in horizontal section before caudal base; 3 scales above lateral line to origin of spinous dorsal; 9 scales below lateral line in vertical row to origin of spinous anal; 19 predorsal scales; width of head 1.5 its length; head depth at occiput 1; snout 4; eye 2.75; maxillary 3.2; interorbital 2.4; fourth dorsal spine 2.12; ninth dorsal ray about 1.75; second anal spine 1.9; ninth anal ray 1.4; least depth of caudal peduncle 2.

Body strongly compressed, deeply ellipsoid, deeper midway in combined head and trunk. Edges all convex. Caudal peduncle well compressed, long as deep.

Head deep, profiles about evenly inclined, with upper very slightly concave over eye, compressed and flattened sides slope evenly above and below. Snout surface convex, also profile, length half its width. Eye, also pupil, slightly ellipsoid, little advanced or with posterior edge about midway in head length. Mouth small, oblique, terminal. Lips narrow, rather thin. Teeth conic, in rather broad bands in jaws, outer row slightly enlarged, also extend all along premaxillary edge. Mandible even with upper jaw tip when closed, rather shallow and rami well elevated behind inside mouth. Buccal membranes (breathing valves) present inside mouth, upper broader. Tongue pointed, free, smooth, rather elongate. Nostril small, simple pore, about midway on side of snout. Interorbital evenly convex. Preorbital narrow, about two-fifths of eye. Suborbital and preopercle edges entire.

Gill-opening forward to anterior edge of eye. Rakers 7+20, lanceolate, but little shorter than filaments and latter slightly less than half of eye. Pseudobranchiæ large as gill-filaments. Isthmus narrowly constricted in front.

Scales large, minutely ctenoid, rather narrowly imbricated, smaller along edges of body. Cheek with 4 rows of scales. Single row of scales on preorbital and infra-orbital. Small scales crowded densely over bases of vertical fins, though on spinous portions forming a sheath basally, row of scales up behind each spine on membrane. Small scales at pectoral base. Ventral with pointed axillary scale about one-third of fin-length, median flap between fins about three-fourths length of axillary flap. Scales with basal radiating striæ 7 to 10, sometimes 2 or 3 auxiliaries; small apical denticles 98 to 110; circuli fine. Upper arch of lateral line extends back opposite eleventh dorsal spine base. Tubes large, simple, each well exposed or over first three-fifths of scale; also continued irregularly as 4 pores, then drops a scale and 2 more pores below soft dorsal. Horizontal section of lateral line of simple pores, begins below soft dorsal opposite third pore of upper section, skips 1 or 2 scales, then continues to caudal base.

Spinous dorsal inserted immediately after pectoral base or much nearer snout tip than origin of soft dorsal, spines graduated up to third and fourth, the longest, others posteriorly but slightly shorter, edge of fin notched and little cutaneous flap behind each spine tip. Soft dorsal inserted about last third in space between origin of spinous dorsal and base of caudal, fin pointed, median rays longest. Spinous anal inserted opposite ninth dorsal spine base or little nearer pectoral origin than caudal base, second spine longer, first two-fifths its length. Soft anal like soft dorsal, only larger. Caudal deeply forked and outermost rays of each lobe produced in long slender points, length 1.87 in combined head and trunk. Pectoral reaches anal, upper rays longest, and fin about 3 in combined head and trunk. Ventral inserted slightly behind origin of pectoral, first ray ends in filament reaching soft anal origin. Ventral spine three-fifths of fin. Vent directly in front of anal.

Color when fresh in alcohol, the front half of entire body is deep blackish brown, hind portion white, line of demarcation very striking or exactly midway between eye center and caudal base. Pectoral base and dorsal jet-black. Iris blackish-brown, golden circle around black pupil.

Length 75 mm. Pago Pago.

Another with same locality shows: Head 3.16; depth 1.87; D. XII, 14; A. II, 13; 14 tubes in upper arch of lateral line; snout 4 in head; eye 2.5; maxillary 3.25; interorbital 2.25; length 60 mm.

Concerning *C. dimidiatus*, Jordan and Seale state: "It is very close to our *Chromis isomelas*, but according to the figure by Dr. Günther, and the description of Dr. Klunzinger, the posterior boundary of the black area is at the front of the anal fin." Turning to Günther's figure of *Heliastes dimidiatus*,[1] one finds such is not the case, as Günther shows the dark anterior area extending almost to the caudal peduncle, at least over a good portion of the soft dorsal and certainly over more than half of the anals. No dark pectoral blotch is indicated, though Günther says that the pectoral base is black. It thus appears that his figure represents a variation of *C. dimidiatus*, and it is quite likely *C. isomelas* is simply another variation. Klunzinger says[2] that the dark anterior color extends to origin of anal, bases of pectorals and ventrals black, pectoral hyaline. He mentions only one example, 60 mm. long, and states that its caudal has elongate points.

LABRIDÆ.

Platyglossus notopsis (Valenciennes).

Three young examples from Pago Pago, quite unlike the adult in coloration. In alcohol our specimens are generally dull brown. Five longitudinal bands, expanded medially, each bordered broadly with blackish-brown so as to form 10 bands all together. Bands on head much narrower and pale areas thus wider. On trunk intervening dark areas of each pair of dark bands mottled or blotched obscurely darker. Dorsals and anals black. Middle of spinous dorsal with large black ocellus, edge narrowly whitish, equal to 1.5 eye diameters. Caudal base with blackish bands extending short space, then end abruptly, rest of fin white. Pectoral with dusky base, fin otherwise gray-white. Ventral dusky. Iris slaty-brown. Largest example 44 mm. Smaller examples show pale brown, general color paler or more whitish, also pale bands much broader. In very young each dorsal white, with 2 black blotches, side with 2 broad longitudinal blackish bands and parallel short band on back and breast. Also bands end on caudal base as black blotch to each caudal lobe. Median blackish band on head above and another below upper forks at interorbital to form band each side of back, and lower extends back to join abdominal band of each side behind. Otherwise coloration whitish or pale.

Also, small example from cove just south of Aua village.

Cheilinus fasciatus (Bloch).

Young example from cove just south of Aua village.

SCARICHTHYIDÆ.

Callyodon rubro-violaceus (Steindachner).

Head 2.33; depth 2.8; D. IX, 10; A. III, 9; scales 19 in upper arch of lateral line, 5 in lower section to caudal base and 2 more on latter; 1 scale above lateral line and 6 below; snout 3 in head; eye 4.25; mouth 6.5; interorbital 3. Three rows of scales on cheek, of which lower row on preopercle limb. Body elongately ellipsoid, com-

[1] Jour. Mus. Godeffroy, VII (Heft. xv), 1881, p. 237, pl. 125, fig. B.
[2] Verh. Zool. Bot. Ges. Wien, XXI, 1871, p. 29.

pressed. Head rather pointed. Eye large, slightly advanced. No posterior canines. Lips wide, upper covering greater part of teeth. Caudal slightly convex behind.

Color in alcohol dull olive-brownish generally, scarcely paler below, and without conspicuous markings, though center of each scale little paler. Dark line on upper lip. Dorsals and anals mottled brownish medianly. Caudal pale brownish, with about 4 very obsolete or faint brownish cross-bars. Iris slaty. Length 46 mm. From coral reef in front of hospital, Pago Pago Harbor.

Head 2.33; depth 2.33 to 2.87, D. IX, 10; A. III, 9; scales 19 in upper arch of lateral line, 4 in lower section to base of caudal and 1 more on latter; 1 scale above lateral line and 6 below; snout 3.25 to 3.33 in head; eye 3.33 to 3.5; mouth 4.5 to 4.66; interorbital 2.75 to 3. Three rows of scales on cheek. Body elongately ellipsoid, compressed. Head pointed. Eye large, slightly advanced. No posterior canines. Lips moderate, teeth broadly exposed. Caudal slightly convex behind. Color in alcohol pale brownish-olive with 4 broad dark-brownish longitudinal bands, expanded medially and broader than pale interspaces, but not so on head. Pale-brown bar down from lower anterior edge of eye, another from posterior edge. Lips dusted brownish. Head mottled brownish above. At caudal base each median dark body-bar ends as blackish blotch at base of each lobe, fin otherwise whitish. Dorsals and anals largely deep dusky, at least basally, rest with other fins pale. Length 27 mm. Two from cove just south of Aua village.

Günther unites this species with *C. ruberrimus* Jordan and Seale, and questionably includes *Pseudoscarus rubro-violaceus* Steindachner and *Scarus paluca* Jenkins.

CHÆTODONTIDÆ.

Chætodon trifascialis Quoy and Gaimard.

Two examples, 20 to 31 mm. long, from coral in reef in front of hospital, Pago Pago Harbor.

Chætodon pelewensis Kner.

One from Pago Pago. A comparison with Günther's figure shows how crude his representation really is. The scales in our specimen are all much finer on the fins, pale ocular bar has dark border above the eye, ends of upper jaw dusky, 7 oblique dark bars but little curved and lowest nearly straight, with one on anal sub-basally, the other close to the body edge, though not extending on caudal peduncle. Row of dark spots between each defined dark bar and parallel.

Chætodon melannotus Schneider.

Young example, 26 mm. long, from coral in reef in front of hospital, Pago Pago Harbor. It agrees largely with Day's figure,[1] except that the ocular bar is broader, no black submarginal dorsal, anal, and caudal line, and the black on caudal peduncle encompasses most all of the fin, leaving only narrow white crescent across caudal base.

Two other examples, 24 mm. long, from cove just south of Aua village.

Chætodon miliaris Quoy and Gaimard.

Four from cove just south of Aua village, largest 23 mm. Close to the young of *C. melannotus*, but differ in slightly less inclined lines on sides of body and presence of blackish ventral and anal edge, last more broad anteriorly.

Holacanthus nicobariensis (Schneider).

One small example from same locality as last.

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[1] Fishes of India, I, 1875, pl. 28, fig. 1.

ACANTHURIDÆ.

Hepatus atrimentatus Jordan and Evermann.

Small example from coral in reef in front of hospital, Pago Pago. Traces of longitudinal blue lines, better separated and fewer than in the original figure.[1] Also only trace of black blotch at bases of last dorsal rays.

Hepatus triostegus (Linnæus).

Four small examples from tide-pools near Double Point, just west of entrance to Pago Pago Harbor. Jordan and Seale say: "This seems like *Hepatus sandwichensis*, but lacks one cross-bar and is very pale, only four bands on sides." Such is not the case with our material, as all are like Jordan and Evermann's Hawaiian figure,[2] except that they all have the dark cross-bar on caudal peduncle above and below, but broken medianly on each side of caudal peduncle. Jordan and Evermann do not show it on the lower surface of the caudal peduncle. Black bar at pectoral base in our examples extending below only slightly, if at all.

MONACANTHIDÆ.

Oxymonacanthus longirostris (Schneider).

Small examples from cove just south of Aua village.

TETRODONTIDÆ.

Canthigaster solandri (Richardson).

Three examples, largest 32 mm., from cove just south of Aua village, tide-pools near Double Point, just west of entrance to Pago Pago Harbor and Pago Pago.

SCORPÆNIDÆ.

Sebastopsis guamensis (Quoy and Gaimard).

Two from Pago Pago, larger 84 mm. Six from cove just south of Aua village, largest 75 mm. Four from coral reef in front of hospital, Pago Pago. These agree with Günther's figure,[3] except that he does not show the supraorbital cirrhus.

Sebastopsis scabra (Ramsay and Ogilby) is said to differ in its longer anal spine, though this is no longer than in our examples if Jordan and Seale's[4] figure is correctly identified. *S. parvipinnis* (Garrett) is alleged to differ in its minute dermal flaps and rather low, uniform dorsal, both characters possibly due to variation.

Sebastapistes laotale Jordan and Seale.

One 53 mm. from coral in reef in front of hospital, Pago Pago. Two, 64 and 46 mm., from cove just south of Aua village. Also another, same locality, screened at the bottom.

GOBIESOCIDÆ.

Crepidogaster samoensis Steindachner.

Two small examples from cove just south of Aua village.

GOBIIDÆ.

Eviota zonura Jordan and Seale.

Two small specimens, same locality as last.

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[1] Bull. U. S. Fish. Comm., XXIII, 1903 (1905), p. 393, fig. 171.
[2] *L. c.*, p. 395, fig. 172.
[3] Jour. Mus. Godeffroy, IV, 1875, pl. 76, fig. c.
[4] Bull. Bur. Fisher., XXV, 1905, p. 375, fig. 71.

Eviota afelei Jordan and Seale.

Six from coral in reef in front of hospital, Pago Pago; cove just south of Aua village; tide-pools near Double Point, just west of entrance to Pago Pago Harbor. Probably *E. smaragdus* Jordan and Seale is identical.

Eviota distigma Jordan and Seale.

Two from cove just south of Aua village. Small black spots, two in number, on each pectoral base distinctive. Two from tide-pools near Double Point, just west of entrance to Pago Pago Harbor.

Pseudogobiodon citrinus (Rüppell).

Twenty examples from cove just south of Aua village. Variably pale or dark. Some with first dorsal olive, border bright orange, edge narrowly black. Second dorsal olive with yellow border, narrowly edged blackish in some examples; others show pectorals with yellowish tints. The darker examples mostly uniform slaty and without the brilliant borders to the fins.

Eleven examples, same locality, screened at the bottom, are variably light and dark, some yellowish, others with orange-bordered dorsal. Three from coral in reef in front of hospital, Pago Pago Harbor, and one from Pago Pago.

BLENNIIDÆ.

Enneapterygius tusitalæ Jordan and Seale.

One from cove just south of Aua village and 5 from tide-pools near Double Point, just west of entrance to Pago Pago Harbor.

Salarias variolosus Valenciennes.

One example from cove just south of Aua village. Jordan and Evermann[1] say: "The fish figured and described by Günther in Fische der Südsee as *Salarias variolosus* from Tahiti[2] is a different species." It is also further inferred that the specimen in the Academy of Natural Sciences of Philadelphia from the "Sandwich Islands," collected by Thomas Nuttall, is not identical with Günther's fish. A comparison of Nuttall's specimen with our Samoan leaves no doubt as to their identity.

Salarias gibbifrons Quoy and Gaimard.

One from cove just south of Aua village.

Alticus biseriatus (Valenciennes). (Fig. 2).

Head 3.33 to 4.12; depth 3.66 to 5; D. XIII, 18 to 20; A. 22 to 24; P. 15; V. 2; head width 1.5 its length; head depth (without crest) 1.4; eye 2.5 to 3.5; mouth width 2; first dorsal spine 2; fifth dorsal ray 1.33; fourth anal ray 2.33; least depth of caudal peduncle 2.33; caudal 1; pectoral 1.25; ventral 2.

Body elongate, slender, tapers back gradually and evenly from head to caudal peduncle. Latter not free, compressed.

Head small, robust, cheeks and lower sides little swollen. Snout very obtuse, front profile vertical and slightly convex, breadth opposite front of eyes about equals twice its length to upper jaw end medially. Eye large, antero-lateral, moderately elevated, posterior edge near first third in head. Mouth broad, with short gape, inferior, so front of lower jaw about opposite eye center. Each side of lower jaw with large posterior canine. Teeth minute otherwise, very close-set, pointed, in single narrow flexible row. Interorbital narrow, not one-third of eye, level. Anterior nostril level with and close before lower eye edge and with short fleshy tentacle about one-third of eye. Posterior nostril close above anterior or lower nostril, also nearer eye, simple pore.

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[1] Bull. U. S. F. Com., XXIII (pt. 1), 1903 (1905), p. 498.

[2] Jour. Mus. Godeffroy, VI (Heft. xi), 1877, p. 203, pl. 116, fig. A.

Gill-opening forms free fold across broad isthmus. Rakers at least a dozen short points, about one-third of filaments and latter one-third of eye.

Body covered with smooth skin. Head with median cutaneous keel or crest in largest individual only, arises opposite posterior edge of pupil and not quite to dorsal origin, its length 1.6 in head. The smaller individuals show a pair of short nuchal tentacles. Long, pointed, fleshy flap above eye 1.5 eye diameters, each edge with several (3 to 5) short tentacles. Row of pores behind eye along suborbitals, another down preopercle, third one on mandible.

Spinous dorsal origin slightly in front of gill-opening edge, only last few spines graduated down short, as deep notch before soft dorsal, and fin largely uniform with entire edge. Soft dorsal with entire edge, large, uniform in height, last ray joined by membrane to upper caudal peduncle edge, but not to caudal fin. Anal origin about opposite tenth dorsal spine base, fin uniform in height, free from caudal peduncle behind, membrane behind each ray tip notched. Caudal rounded. Lower median pectoral rays longest, fin almost reaches anal. Ventral inserted slightly in front of pectoral origin, inner ray slightly longer, halfway to anal origin.

Color in alcohol dull lavender-brown generally on back, lower and under surface pale or whitish. Trunk with a dozen dusky-brown vertical blotches somewhat arranged as if in pairs, joined above alternately on back with small, dusky, vertical

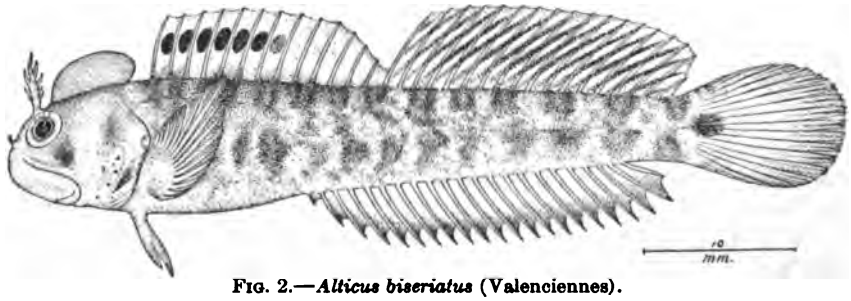

FIG. 2.—*Alticus biseriatus* (Valenciennes).

blotches extending up somewhat on bases of dorsal fin. On head dusky clouded blotch behind eye, one on opercle, one on cheek below, one from edge of lower eye to mouth, and one on snout. Number of indistinct, small brownish ocelli, much less than pupil, on head. Crest dusky, mottled paler. Trunk mottled with scattered paler dots and obscure marblings. Fins largely grayish, spinous dorsal with membranes medianly anteriorly, or until seventh, with jet-black round blotch little less than eye, and on rest of fin gradually become pale dusky behind. Soft dorsal, except base, with many even oblique pale gray-blue lines, up and backward. Caudal with dark blotch little less than eye at bases of median rays, lower and submarginal part of fin dusky. Anal with long submarginal dusky band. Dark obscure transverse streak at pectoral base.

One specimen, 50 mm. in length, from tide-pools near Double Point, just west of entrance to Pago Pago Harbor, March 20, 1917, and three specimens, 21 to 30 mm., same locality.

Salarias rivulatus Rüppell.

Eleven dark examples, largest 98 mm. Pago Pago.

Enchelyurus ater (Günther).

Two from cove just south of Aua village. Jordan and Seale state that "Günther describes the ventrals as reaching the anal, but in his figure the fins are much shorter." This is probably a variation with age.

FIERASFERIDÆ.

Jordanicus parvipinnis (Kaup).

One, same locality as last.

VIII.

LEODICIDÆ FROM FIJI AND SAMOA.

By A. L. TREADWELL,
Professor of Zoology in Vassar College.

Eight plates and 68 text-figures.

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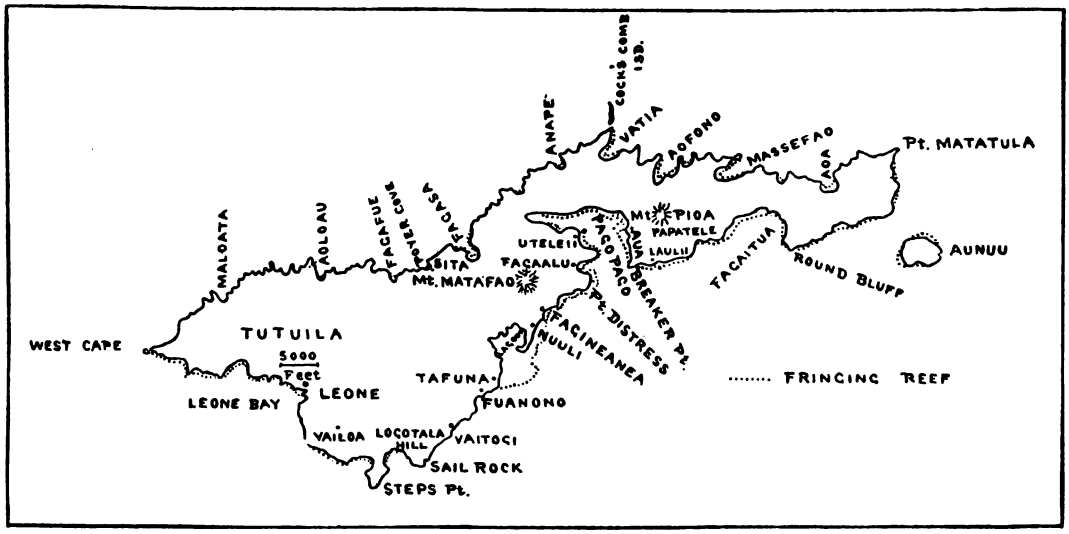
LEODICIDAE FROM FIJI AND SAMOA.

By A. L. Treadwell.

INTRODUCTION.

The annelids here described were collected by the writer in Fiji and Samoa in April, May, and June of 1920, on an expedition conducted by the Department of Marine Biology of the Carnegie Institution of Washington, Dr. A. G. Mayor, Director. Owing to our short stay in Fiji, collecting there was limited to the immediate vicinity of Suva and was mainly done on the reefs on either side of the main entrance to the harbor and on the mud flats near the city front.



Map of Tutuila, American Samoa.

In Samoa, a very thorough survey was made of the harbor of Pago Pago in Tutuila, so that so far as the Leodicidæ are concerned this work can claim to be exhaustive for that locality. Only a few annelids from other families were collected and none equaled the Leodicidæ in number of species or abundance. The Leodicidæ occur especially in the reef rocks and are not represented in the mud of the upper harbor. Apparently this is due to the large quantities of fresh water which flow into the upper end of the harbor, making a brackish-water condition in which only a few Terebellids and Capitellidids can live. I found a similar condition at Fagaalu and

on the opposite side of the island in the harbor of Leone. Collections were also made in the lagoon southwest of Nuuli and in the reef west of the island of Aunuu.

The specimens were narcotized in a solution of $MgSO_4$, 153 grams to the liter, killed in 10 per cent formalin, and preserved in strong alcohol.

SYSTEMATIC DESCRIPTIONS.

In an earlier paper (Treadwell, 1921*a*) I have discussed the anatomical features which are of most importance in the taxonomy of the Leodicidæ, and later study has led to no conclusions different from those there stated, unless it is to further emphasize the importance of the jaw in classification. I found the general character of the jaw remarkably constant in any one species, especially in the form of the plates and their color. Multiplication of genera and subgenera on the part of taxonomists is a very unfortunate habit, but there would be some justification for making a subgenus of *Leodice* to include *L. siciliensis* Grube, *L. caribæa* Grube, *L. paloloides* Moore, *L. viridis* Gray, *L. viridis* var. *vernalis* Treadwell (see page 123), and *L. dubia* Woodworth, on the basis of their jaw structure. In the relatively large size of the mandible, the limited tooth development on the proximal plates, and the peculiar appearance of the distal ones, these differ from all others that I have seen.

Students of this group have not agreed on the major classification of the animals included in it. In an earlier paper (Treadwell, 1921*a*) I followed what seemed to be the majority opinion and classified the Leodicidæ as a family, with the subfamilies Leodicinæ, Lumbrinereinæ, and Stauronereinæ. Chamberlin (1919*a*), in a paper which appeared after mine had gone to the editor, constructs the superfamily Leodicoidea, putting under it the families Leodicidæ, Lumbrinereidæ, Onuphididæ, and Dorvilleidæ (=Stauronereidæ, see page 166). In the present paper I shall follow my original arrangement.

Family LEODICIDÆ.

Annelida varying much in size in different species, with or without prostomial tentacles, nuchal cirri, eyes, and parapodial gills. Notopodium of parapodium rudimentary or apparently absent. Jaw of maxilla and mandible, the former of two or more rows of plates, mostly toothed.

Subfamily LEODICINÆ.

With dorsal and ventral parapodial cirri, with or without nuchal cirri and parapodial gills. Prostomium with from 1 to 7 tentacles and one pair of palps more or less fused with the prostomium.

Genus LEODICE Savigny.

Savigny, J. C., Systeme des Annelides 1930, p. 13.

Prostomium 2- or 4-lobed, the lobing often obscure. With 5 tentacles and 1 pair of eyes. A pair of nuchal cirri on the second body-somite. Parapodia begin on the

third body-somite. Gills on more or fewer of the body somites. Jaw of maxilla and mandible, the former of forceps, 2 pairs of toothed plates, and 1 unpaired plate. Mandible of symmetrical halves joined anteriorly to form a cutting edge. One or two pairs of anal cirri.

Leodice viridis Gray.

Plate 1, figures 1 to 7; text-figures 1 and 2.

Palolo viridis Gray, Stair, 1847, pp. 17–18.
Palolo viridis Macdonald, 1858, pp. 237–239, pl. 41.
Lysidice palolo Quatrefages, 1865, p. 379.
Lysidice viridis Ehlers, 1864–1868, p. 367, pl. 16, figs. 17, 18.
Lysidice viridis Collin, 1897, pp. 164–174. (Reprint pp. 1–11.)
Palolowurm Friedländer, 1898, pp. 337–357.
Eunice viridis Ehlers, 1898, pp. 1–16.
Eunice viridis Woodworth, 1907, pp. 3–21, pls. 1–3.

Fully mature specimens were not found, and no measurements can be given of the completely grown individuals. One specimen measured, after preservation, 270 mm. in length and contained about 450 somites.

The prostomium (plate 1, fig. 1) is noticeably 2-lobed, and when expanded is a trifle wider than the peristomium. Dorsally it is colored a yellowish brown with many minute yellow spots, the anterior margins and the ventral surface being colorless. The tentacles are colorless, blunt-pointed, and more or less wrinkled, the median one reaching as far as the anterior border of the fifth somite, the inner paired to the middle of the third, the outer paired to the second. Ehlers (1898, p. 5) is in error in describing the tentacles and cirri as jointed. The eyes are large. The peristomium is a little longer than the prostomium; its anterior margin bends around on either side so as more or less to inclose the bases of the tentacles. It is colored much like the prostomium, the pigment extending over the lateral faces but leaving the ventral surface uncolored. The second somite is colored much like the first, but on its anterior border has an uncolored band a little wider than the bases of the nuchal cirri. The nuchal cirri are without color and extend about as far as to the anterior border of the prostomium. The color is continued as far as the region of somites 18 to 20, but the anterior colorless band in each somite becomes successively broader, so that behind the region of somite 20 the only body-color is that given to it by the contents of the intestine or, in the posterior portion, the color of the sex organs. In very young animals, where the sex products have not formed in sufficient quantities to produce a color, this posterior region is colorless. In the posterior third of the body, except for the extreme posterior end, each somite has a median ventral black spot. Woodworth (1907, plate 1) gives colored figures of the species. I was unable, owing to the time of my visit to Samoa, to collect the epitokous ends, but Woodworth's figure 3 corresponds very well with my observations.

There are two pairs of anal cirri, the ventral ones much the smaller (plate 1, fig. 2).

Throughout the median region the gills appear as single filaments larger than the dorsal cirri, to whose bases they are attached (plate 1, fig. 3), and in life are a bright red color. In a specimen 250 mm. long the gills first appeared at the region of somite 137 and continued to about 180 somites from the pygidium. The first and last of the series are the smallest and are not very prominent, but through the middle region, where the gills are largest, they are prominent because of their color.

The first parapodium has very prominent dorsal and ventral cirri and a very small setal lobe, the latter with vertical, parallel, anterior and ventral lips. Two aciculæ, one much darker than the other, extend into the setal lobe, and there is a small tuft of setæ containing both simple and compound forms. On subsequent parapodia there is a relatively great increase in size of the setal portion, and at the same time a shifting of parapodial position, so that they come to lie higher on the lateral face. The first parapodia, because of their ventral position, are partly hidden from a dorsal view

and appear to be no larger than the others. The tenth parapodium (plate 1, fig. 4) has a prominent setal lobe with its anterior lip asymmetrically bifid and with a rounded posterior lip. There is a single very large black acicula. Dorsally in the seta tuft are a few long, slender, simple setæ and ventral to these a dense tuft of compound ones with heavy basal portions and relatively short but stout terminal joints. The dorsal cirrus is very slender, the ventral one short, carried on the end of a pad-like swelling. I could find no trace of needle aciculæ.

Throughout the anterior region of the body this ventral pad-like swelling, which appears at the region of somite 10, is continued and the pads on the two sides of each somite, together with the flattened ventral surface, make up a sole-like ventral region which is in marked contrast to the rounded dorsal region. The pads disappear in the gilled somites, but the flattened ventral surface persists. A gilled parapodium (plate 1, fig. 3) has a pointed setal region with a single large acicula. The gill is attached to the base of the dorsal cirrus and when fully developed is much larger than the cirrus.

As is well known, this species develops at the approach of the breeding-season a posterior epitokous region, and consequently the form of the posterior end depends on the degree of development of the epitokous portion. The swarming occurs in October and November, and my collections were made in April, May, and June, so that the epitokous modifications had appeared only to a limited extent. According to figures given by Friedländer (1898, p. 344) and Woodworth (1907, plate 2, fig. 10), the epitokous portion is much narrower than the atokous, as if a shrinking in diameter occurs at this time. This is contrary to the conditions found in *Leodice fucata* Ehlers (the Atlantic Palolo, in which a swarming occurs), to *L. paloloides* Moore, to *L. caribæa* Grube, and to *L. viridis* var. *vernalis* (see page 133), where, when the sex products are formed, the posterior region is much broader than the anterior. Swarming has never been observed in these latter species, but (except for this question of absolute width) the structural modifications are quite as they are in the true Palolo.

I am indebted to Lieut. Commander R. C. Reed for specimens of swarming ends collected in Tutuila, Samoa, in November 1920. In these the setæ appeared to be longer than in the atokous phase, but careful measurements showed that the absolute length is the same, though because of the narrowing of the body diameter, they extend to a greater distance from the surface. A parapodium from the epitokous region is shown in plate 1, figure 5. The setal lobe is pointed and has a large conical ventral cirrus attached near the end of the lobe. The dorsal cirrus is attached much farther back from the apex, and while conical is much narrower than the ventral one.

The aciculæ are all of one kind, straight and bluntly rounded at the apex. They may be nearly colorless, as happens in the case of the smaller ones, or contain brown pigment, which may be very dense but never appears black. The setæ are of two kinds, simple and compound, and are similar in form throughout the body. The simple ones (text-fig. 2) are long and sharp-pointed, minutely denticulated along one edge. The compound ones (text-fig. 1) have relatively heavy basal joints which are denticulated at their apices, the terminal joints small, with equal-sized apical and subapical teeth covered by a hood which is minutely serrated along its border.

The maxillæ (plate 1, fig. 6) are dark, with the carrier much lighter than the remainder. The two halves of the carrier are closely united throughout most of their extent, the basal ends rounded and relatively broad. The forceps has a heavy basal portion narrowing very abruptly to form the fang at about the middle of the plate. The proximal plates are large, extending back to the carriers; the left one has 3, the right one has 2, indistinctly marked-off teeth. The forceps and proximal plates are very dark in color, with a whitish incrustation along the cutting edges. Distally are 2 plates on the right side and 3 on the left. These are very irregular in outline and their apparent form and size depends on the position from which they are viewed, more than is the case in the majority of Leodicid maxillæ. Their general appearance is shown in figure 6 of plate 1. As compared with the maxilla, the mandible is very large (plate 1, fig. 7) and its lateral margins are much rolled. To the naked eye or under

very low magnification the mandible is an intense white and, as in the case of *L. caribæa* (Treadwell, 1921, p. 49), when protruded from the mouth, forms an easily recognized diagnostic character of the species. Under higher magnification the center shows dark.

Leodice viridis belongs to the group of the Leodicidæ of which *L. siciliensis* is a representative species, all distinguished by the small development of the gills, the peculiar jaw apparatus and in most species by the formation of an epitokous posterior end possibly in all cases connected with a swarming. Swarming has actually been seen only in *L. viridis* and *L. dubia* (Woodworth, 1907), but it seems possible that it occurs in the other species as well. (See Treadwell, 1921, p. 47). The only other known case of swarming among the Leodicidæ is that of *L. fucata*, which occurs generally in the West Indian region, where it has been reported on by Mayor (1902) and by Treadwell (1921*a*, p. 43–47, pl. 4, figs. 5 to 10, text-figs. 127 to 135). *L. fucata* is not, however, a member of the *siciliensis* group.

As my collecting was done some months earlier than the swarming period, I was unable to make any observations on this phenomenon and can add nothing to the literature, which is well summarized by Woodworth (1907). In collecting at the spring tides of April, May, and June successively, where low water made it possible to get near the outer edges of the reefs, I found indications of a gradual change toward the epitokous condition in the change of color due to the developing sex products, but these changes were comparatively slight. Dr. Mayor very kindly collected the species in July and reported that there was little change in color from the June condition.

My collections were all made on the reefs in and near Pago Pago Harbor in Tutuila, Samoa. The animals were to be found in rocks at all distances from the shore, but were larger and evidently more mature the farther from shore they were collected, my largest specimens being obtained at as near the edge of the reef as it was possible to go. This led to the suggestion (Treadwell, 1921, pp. 199, 200) that the rate of development may depend on the environment and that those living near shore find the conditions so unfavorable that they grow very slowly and possibly never mature. In all respects except size, these resemble those from farther out, so that there is no question as to the identity of species. I made careful studies of those localities where both the native Samoans and residents at the U. S. Naval Station told me the swarm is most numerous in October and November, but found no place where they are as abundant in the rocks as they should be to supply the enormous number of epitokous ends which appear at the swarming. It seems to me probable that the largest individuals and the greatest number of individuals are to be looked for on the edges of the reefs, where, on account of the surf, I was unable to collect.

Leodice viridis var. vernalis, new variety.

Plate 1, figures 8–11.

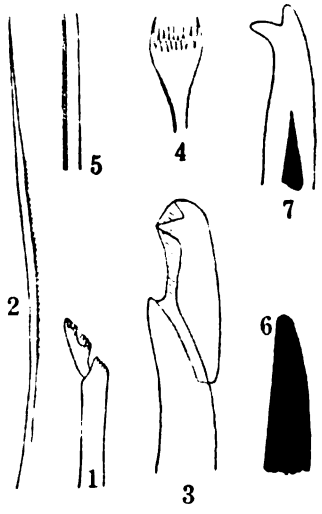
A considerable number of a small *Leodice* were collected in Suva Harbor, Fiji. Many were in the epitokous condition, with bright green eggs in the posterior part of the body. These belong to the *siciliensis* group and I at first took them for the Palolo, though puzzled by their sexual condition. As this was in April, and the first swarming would be in October, the mature condition of the eggs was hard to understand. Later the true Palolo was collected in Samoa, but it was not until a more careful examination of my collections was made after my return from the expedition that I detected the differences between the species and the variety. (In my report, (1921*b*, pp. 199, 200) I erroneously confused the two.) The variety does not appear in my Samoan collections, but as I was intent on collecting the largest individuals, I may have passed it over on the assumption that it was the young of the true Palolo. I do not, however, think that it occurs in Samoa, as if it had been there and as fully mature as were the Fijian forms I could hardly have failed to notice it.

The living animal has at the anterior end an intense greenish-brown color with much iridescence which is continued with a gradual diminution in intensity to the

region of somite 50. The prostomium is broader than the peristomium (plate 1, fig. 8) and decidedly 2-lobed, its dorsal surface dark in color, the anterior margin and regions lateral to the eyes being colorless. The tentacles are colorless, the median one 4 to 5 times as long as the prostomium and pointed at the apex. The tentacles are more sharply pointed and have longer cirrophores than in *L. viridis*.

Preserved material retains the coloration of the anterior end, so that for about the first 40 somites both dorsal and ventral surfaces are dark brown. The anterior somites do not have the colorless band on their anterior borders which are present in *L. viridis* (compare fig. 1 and fig. 8, plate 1). The parapodia are uncolored, as are the nuchal cirri. In the epitokous portion there is on either side of the dorsal surface in each somite a dark spot at the base of the parapodium (plate 1, fig. 11). Apparently these spots do not extend to the very posterior end, but I could not determine this with certainty in the material at my disposal. They may also be found on a few of the posterior atokous somites.

A parapodium from setigerous somite 10 is shown in plate 1, fig. 10. The prominent pad-like swelling which carries the ventral cirrus begins at about this region and extends for about the first quarter of the length of the animal. The gills have about the same arrangement that they have in *L. viridis*, but are more slender, extend into the epitokous region, and are relatively more prominent. A small *L. viridis* may be distinguished from one of the variety of the same size by the fact that the gills in *viridis* would be much smaller than in the variety.



TEXT-FIGURES 1 TO 7.

1 and 2. *Leodice viridis*. 1, compound seta × 260; 2, simple seta × 220.

3 to 7. *Leodice aphroditois*. 3, compound seta × 220; 4, pectinate seta × 220; 5, detail of simple seta × 220; 6, acicula × 220; 7, ventral acicula × 220.

An epitokous parapodium (plate 1, fig. 11) has a small dorsal cirrus with the long gill attached near its base. There are two pairs of anal cirri quite similar to those of *L. viridis*, the jaws, except for size, are exactly like those of the species, and the setæ and aciculæ are similar to those of the species.

The type is in the American Museum of Natural History.

Leodice aphroditois Pallas.

Plate 1, figures 12 to 17; text-figures 3 to 7.

Nereis aphroditois Pallas, 1788, p. 229, pl. 5, figs. 1–7.
Eunice aphroditois Ehlers, 1864–68, p. 306, pl. 15, figs. 23–29.
Eunice aphroditois McIntosh, 1885, p. 282, pl. 38, figs. 16, 17; pl. 20A, figs. 8–10.
Eunice aphroditois Crossland, 1904, p. 288.
Eunice aphroditois Augener, 1913, pp. 267–270.
Eunice aphroditois Fauvel, 1917, pp. 215–220, pls. 7, 8.

References to a considerable literature concerning this species and a related or more probably identical form *L. kinbergii* will be found in the works cited above. As the material at my disposal did not enable me to attempt this question of the synonymy, it does not seem necessary to undertake any discussion of the subject.

Two specimens were collected at Pago Pago, Samoa, the smaller one 220 mm. long, with a prostomial width of 6 mm. and a larger one 450 mm. long, for the part which was preserved, a considerable portion of the posterior end having been lost. The prostomial width is 8 mm.

The smaller individual in life was very dark brown, almost black. The prostomium was lighter brown in color, the peristomium greenish brown, with longitudinal black markings, and very iridescent. The tentacles were greenish brown, with white bands not regularly arranged and not uniform on the different tentacles. The remainder of the body was dark purplish-brown, becoming purple at the pygidium. There is one pair of stout purple anal cirri uncolored at their apices (plate 1, fig. 13). The larger individual was quite uniformly dark brown, with a greenish tint at the auterior end. The tentacles were faint green, with a darker tip, as were the dorsal cirri. The cirri were not banded. The fourth and fifth setigerous somites were lighter in color than the others, but did not show a distinct "collar." In alcohol, both specimens are brown, though the larger is the darker, and more color is retained in the tentacles. Both show numerous purple lines and streaks running longitudinally on the dorsal surface.

The prostomium (plate 1, fig. 12) is wider than the peristomium and very noticeably 4-lobed. The tentacles are all of about the same length, about as long as the peristomium. The latter is slightly wider anteriorly than posteriorly, with straight margins, and is as long as the following 5 somites. Somite 2 is very short and the nuchal cirri are shorter than the peristomium.

The first parapodium has the usual form, with a large dorsal and a smaller ventral cirrus, with a very small setal lobe. Two good-sized aciculæ extend into the dorsal cirrus, and there is one in the setal lobe. The tenth parapodium (plate 1, fig. 14) has a gill of 16 branches, a very heavy dorsal cirrus, which is longer than the gill, a small acicula in the dorsal cirrus, and a very large one in the setal portion. A parapodium from the posterior end of the body (plate 1, fig. 15). still shows the relatively very large dorsal cirrus and, in addition to the acicular equipment of the anterior ones, there is a ventral hooked acicula.

In the smaller specimen the gills begin on the sixth setigerous somite (the entire body having 180) and extend through about 120 somites. In the larger specimen they arise on the fifth somite on the right and sixth on the left, but as the posterior end is lost I am unable to give their extent. The basal portion of the gill is thick, giving it a heavy appearance during life, but the branches are relatively small and short.

The compound setæ (text-fig. 3) are stout with a heavy shaft and a 2-hooked terminal joint. In the anterior somites they are arranged in a formidable vertical row, but diminish in number in the posterior somites. The pectinate setæ (text-fig. 4) are small and slender, with about 10 teeth on the margin. The simple setæ are very long and slender, with a slender basal portion, widening slightly just outside the parapodial margin, and beyond this tapering gradually to an acute point. Along one edge is a marginal wing, having very fine denticulations. A detail of the shaft is shown in text-figure 5. The dorsal aciculæ are blunt-pointed (text-fig. 6), the ventral ones 2-hooked, with an uncolored apex and a very dark shaft (text-fig. 7).

The maxillæ (plate 1, fig. 16) have a short carrier, with long, slender forceps. The proximal paired plates have each 5 teeth, the right paired with 9, the left with 3, the unpaired with 6. All plates of the maxilla are very black. The shafts of the mandibles are slender, but widen decidedly toward the cutting edge, and are very black in color. The beveled portion is covered with a white incrustation (plate 1, fig. 17).

Although this species has received much attention, it seems worth while to add the above description, because, while I have no doubt as to the accuracy of the identification, the various descriptions which have been written vary so much from each other and from the specimens from Pago Pago that this must be a very variable species, and it seems desirable to record as far as possible these variations. Ehlers's figures are not very satisfactory, especially of the jaws, and the figure he gives of the simple seta shows much more of a broadening in the shaft than I have seen. He gives two figures of pectinate setæ, with 7 teeth in one and 20 in the other. He figures no ventral acicula. He states that the gills are longer than the dorsal cirrus, which is not true in

my specimens. McIntosh figures the nuchal cirri as much shorter than in Ehlers's or in mine, but his figure of the compound seta agrees with that of mine. Augener records a specimen of this species from Samoa, in the collections of the Göttingen Museum, but gives no description of it. Fauvel describes the gills as longer than the dorsal cirrus, while Crossland states that in spite of the large number of their branches, the gills really cover only a small portion of the dorsal surface. This agrees with my specimens from Pago Pago.

Leodice antennata Savigny.

Eunice antennata Crossland, 1904, pp. 312–318, pl. 22, figs. 1–7, text-figs. 56–60.
Eunice antennata Augener, 1913, pp. 270–274.
Eunice antennata Fauvel, 1917, pp. 225–228, text-figs. 20*a*, 20*b*.
Eunice antennata Fauvel, 1919, p. 377.

Figures are given by Crossland, and discussions of the possible synonymy of the species will be found in the first three of the above references.

Two individuals were collected in Pago Pago Harbor, in rock near the landing in front of Cook's Hotel. In life they are brownish green in color, but rather translucent, so that the contained blood modifies the tint very decidedly. The dorsal surface of the prostomium is uncolored except for a purple band around the base of the median tentacle and a similar one around the bases of the inner paired tentacles. From each of these latter a band runs toward the median line, uniting with a broader greenish band which runs toward the anterior margin. On either side of this stripe is a colorless spot. The tentacles and all cirri are articulated, and on the tentacles and anal cirri, but not on the dorsal, are brown bands in the constrictions. From the eighth somite posteriorly a black spot is present in each somite near the dorso-lateral margin, and the smaller of the two shows traces of dorsal white spots toward its posterior end. None of the color remains in the preserved material. The animals are much more active than is usual in this genus, squirming much as does *Nereis* when captured. Crossland (pp. 313, 314) mentions the green color as an occasional variation, possibly in relation to environment, and also comments on the activity of the animals when handled.

The larger of the two specimens is 65 mm. long, and has a peristomial width of 1.5 mm. The other individual is about one-third smaller. The larger one contains immature eggs, so must be adult. The first gill, of 2 branches, is on the fourth setigerous somite. The number of branches rises to 6 in the region of somites 15 to 20, through the middle of the body it drops to 2, and at the extreme posterior end of the body rises again to 4. Only the last 2 or 3 somites are free from gills. The jaws are very delicate, only their margins colored. The proximal paired plates have 6 teeth on the left and 8 on the right, the distal paired plates have 10 on the left and 8 on the right, and the unpaired has 9.

The distinguishing features of this species are the articulated tentacles and cirri, the median tentacle being long (in the larger of my two specimens it reached somite 8); the peculiar arrangement of gills whereby the number of filaments decreases throughout the middle of the body to increase again at the posterior end; and the fact that the ventral acicula has a trifid apex. Crossland's text-figure 60 (p. 317) shows this arrangement of gills, but the dorsal cirri are represented as non-articulated. As this is not in agreement with figures 1 and 7 of his plate 22, it is probably an error in the drawing. Fauvel (1919, p. 378) says that the tridentate aciculæ are rare in specimens from Madagascar, but they are mentioned as distinctive in his Australian specimens (Fauvel, 1917, p. 226, figs. 20*a*, 20*b*), and they are present in my Samoan material.

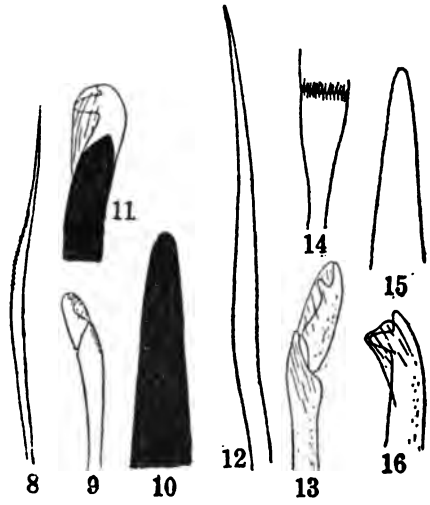
Leodice flava-punctata, new species.

Plate 2, figures 1 to 7; text-figures 8 to 11.

Several specimens, none entire, were collected in Pago Pago Harbor, Samoa. The general appearance of the animals would indicate that they are immature, but the fact that several contain eggs indicates that they are adults. One individual

(in 3 pieces) measures altogether 50 mm. in length, has a prostomial width of 1.75 mm., and contains about 250 somites. The specific name is given because of the yellow spotting which is common in *Leodice*, but the spots are unusually prominent in this species.

The general body-color of the anterior end is dark brown, darker on the prostomium than elsewhere and gradually lightening posteriorly, the color disappearing entirely in the region of from somites 40 to 60. In the peristomium the color is continued on to the ventral surface, but in all other parts it is limited to the dorsal. Scattered over the surface of this brown are numerous yellow dots. In the type a prominent uncolored band extends along the median dorsal line of the prostomium and is continued on to somite 2 (plate 2, fig. 1). Somites 3, 4, and 5 have each a prominent uncolored spot toward the posterior dorsal border and somite 6 is uncolored. In other individuals these colorless spots are either only faintly indicated or are absent. Toward the posterior end of the body each somite is marked by a very narrow purple line across its posterior dorsal margin. One specimen was regenerating a pygidium which had one pair of short, colorless anal cirri. The tentacles are light brown except for the apices, which are uncolored, as are the nuchal and other cirri.



TEXT-FIGURES 8 TO 16.

8 to 11. *Leodice flava-punctata.* 8, simple seta × 285; 9, compound seta × 285; 10, ventral acicula × 285; 11, dorsal acicula × 250.
12 to 16. *Leodice suviensis.* 12, simple seta × 250; 13, compound seta × 250; 14, pectinate seta × 250; 15, dorsal acicula × 68; 16, ventral acicula × 68.

The prostomium (plate 2, fig. 1) is noticeably bifid, and when expanded is a little wider than the peristomium. The latter is a trifle wider than long and slightly concave along the lateral margins. Somite 2 is about one-third as long as 1 and sharply marked off from it. The tentacles are shorter than the peristomium, with inconspicuous cirrophores, and the eyes are so surrounded by pigment as to be scarcely visible. The nuchal cirri are slender and much shorter than the peristomium.

The first parapodium (plate 2, fig. 2) has a bilobed setal portion, with heavy cirri, the ventral cirrus being especially large. There is a single acicula, also needle aciculæ in the dorsal cirrus. The eleventh parapodium (plate 2, fig. 3) has a very prominent setal portion, with a dense tuft of compound setæ ventrally and a smaller tuft of simple setæ dorsally. There is a needle acicula in the dorsal cirrus. The dorsal cirrus is slender, but the ventral one is short and thick and merges gradually into the ventral pad-like swelling characteristic of the anterior parapodia in this genus, but especially prominent here. A later parapodium from behind the middle of the body (plate 2, fig. 4) has a conical setal portion with a prominent ventral swelling, carrying the short, thick ventral cirrus on its outer end. The dorsal cirrus is very slender, and the gill arises from the body-wall dorsal to its base. There is a single pointed acicula in the middle of the setal lobe, and a hooked one near its ventral surface. A few small needle aciculæ extend into the dorsal cirrus.

In a small specimen the gills arise as a single filament on the thirteenth setigerous somite and in the great majority of later somites there are two and three branches

(plate 2, fig. 5), with an increase posteriorly of the number of two-branched gills, but at about somite 40 the number is reduced to one. About 100 of the posterior somites of the specimen are without gills, but I have no information as to the original number of somites in the entire animal. On the right side of somite 16 the gill has 7 branches, and there are 6 on the left of somite 21. This large number of branches, limited to only a single somite, is a very unusual condition. In an individual twice the size of the one just described I could find no gill with more than 6 filaments. The filaments remain relatively large to the end of the series and the blood-vessel in each is especially prominent.

The simple setæ (text-fig. 8) are very slender, only slightly broadened toward the end and taper to acute apices with very minute denticulations along one border. The compound setæ have small terminal joints, the subapical tooth the larger, and with small denticulations along the end of the basal portion (text-fig. 9). Figure 9 is drawn from a seta from the anterior end of the body. In the posterior region the compound setæ have longer terminal joints. The pectinate setæ have about 20 slender teeth, the one at one end of the row longer than the others. The dorsal aciculæ (text-fig. 10) are bluntly rounded at the apex and dark-colored to the very tip. The ventral ones have the tip uncolored, with bluntly rounded teeth covered by a hood (text-fig. 11).

The forceps and margins of all plates of the maxilla are dark brown, while the remaining portions are much lighter. The carriers (plate 2, fig. 7) are short, the forceps long and much curved. This curvature is not adequately represented in the figure, for the forceps are drawn as pointing upward. The proximal paired plates have 5 teeth on the left and 4 on the right; the distal paired have 9 on the right and 5 on the left, 2 of these being much smaller than the others. The unpaired has 8. Beyond the paired plates are rounded pigment patches in the chitin. The mandibles (plate 2, fig. 6) are rather small and slender, the beveled portion being marked with pigment on the outer and inner margins and with concentric lines on the surface.

In structure of gill this species resembles Chamberlin's *L. lita* (1919*a*, pp. 240–244, pl. 54, figs. 6–10; pl. 55, figs. 1–7), but in general body-coloration, form of the peristomium, and character of jaws the two are unlike.

The type is in the American Museum of Natural History.

Leodice suviensis, new species.

Plate 2, figures 8 to 13; text-figures 12 to 16.

A single specimen, collected in rock exposed at low tide on the west side of Rat Passage, in Suva Harbor, Fiji. It measures after preservation 370 mm. in length, has a prostomial width of 4 mm., and at somites 9 and 10 is 9 mm. wide.

To the naked eye the living animal appears very dark, nearly black, while under a hand lens the color is seen to be dark purple, with numerous dirty-white spots over the surface. The tentacles are dark green, uncolored at the tips. All of the cirri have uncolored tips. In preserved material the color is a dark brown, with numerous yellow spots over the surface and a considerable iridescence. The prostomium is rather small, 2-lobed, the tentacles smooth, short, and tapered gradually toward the apices. The unpaired tentacle extends as far as the anterior border of somite 3, the inner paired tentacles are about three-quarters as long as the median, the outer paired about half as long. The outer paired have their bases of attachment noticeably farther forward than the inner ones. The eyes are in the usual position (plate 2, fig. 8).

The peristomial width is to its dorso-median length about as 5 to 3, and its antero-lateral border has a prominent lip on either side. Somite 2 is about one-quarter as long as somite 1, the nuchal cirri extending to about the middle of somite 1. The ventral surface of the anterior region of the body is a little lighter in tint than the dorsal, but otherwise is colored like the dorsal. In the type the pygidium is apparently

regenerating; it has one pair of very short anal cirri colored like the anterior cirri and tentacles.

The gills arise as 2 branches on the right side and as 3 branches on the left side of somite 11 and extend throughout approximately 160 somites. The tenth parapodium has on the right side a gill with 5 filaments (plate 2, fig. 9). From setigerous somites 20 to 60 the gills are long enough to meet across the dorsal surface and may have as many as 9 filaments, but throughout the greater number of the posterior gills the number of filaments is reduced to 1.

The first parapodium has a thick dorsal cirrus, slightly smaller than the nuchal cirri, but otherwise similar to them in form. There is a very small setal lobe and a thick ventral cirrus. Parapodium 10 has a rounded postsetal lobe, the presetal with a concave margin (plate 2, fig. 9, posterior view); there are 2 very black aciculæ. The dorsal cirrus is finger-shaped, with the 5-branched gill arising at its base. The ventral cirrus is conical, on the end of a very prominent pad-like swelling. I was unable to find any needle aciculæ in the dorsal cirrus.

The fiftieth parapodium (plate 2, fig. 10) is not very different in general outline from the tenth, though the ventral cirrus is smaller. This difference is exaggerated in the drawing because the cirrus is partly under the ventral lobe and does not entirely appear. The dorsal cirrus is short and seems to arise from the base of the gill, the latter being so much greater in diameter than the cirrus. There are 2 dorsal aciculæ and 1 ventral one. The gill has 8 filaments arising from a base which is very thick at the point of attachment, but narrows toward the apex. A posterior parapodium (plate 2, fig. 11) is broadly rounded in profile, with very little distinction between anterior and posterior lips. The cirri are small. There are 2 aciculæ, 1 dorsal and 1 ventral, both very black.

In the tenth parapodium there is a tuft of simple setæ with a few pectinate, and a ventral tuft of compound ones, this latter tuft being much stouter than the other. A few of the simple setæ were bilimbate, but this did not show in all cases. In the fiftieth parapodium the pectinate setæ show an increase in number over the conditions found in the tenth, with a corresponding decrease in the number of simple ones. In posterior somites the pectinate setæ are more numerous than the simple ones and have extremely long stalks extending beyond the apex of the dorsal cirrus.

A simple seta from the tenth parapodium (text-fig. 12) is very slightly widened and curved toward the end. In the one drawn the margins are smooth, in others there is a marginal fin. The compound setæ have rather heavy stalks, the terminal joints with apical and subapical teeth covered by hoods with smooth margins (text-fig. 13). The pectinate setæ have about 16 teeth, the terminal one at one end of the row being longer than the others (text-fig. 14).

The dorsal aciculæ are bluntly rounded at the apex (text-fig. 15); the ventral ones have terminal and subterminal teeth, the latter the larger; the apices are hooded (text-fig. 16).

The maxilla (plate 2, fig. 12) is very dark, showing in the translucent portions a lighter brown. The carrier is large relative to the forceps. The proximal paired plates have 5 teeth on the right and 5 on the left, the distal paired have 8 on the right and 6 on the left; the unpaired has 7. The mandible is lighter brown in color than is the maxilla, but has longitudinal brown stripings in each of the basal halves. The beveled portion has concentric lines (plate 2, fig. 13).

The type is in the American Museum of Natural History.

Leodice tubicola, new species.

Plate 3, figures 1 to 6; text-figures 17 to 23.

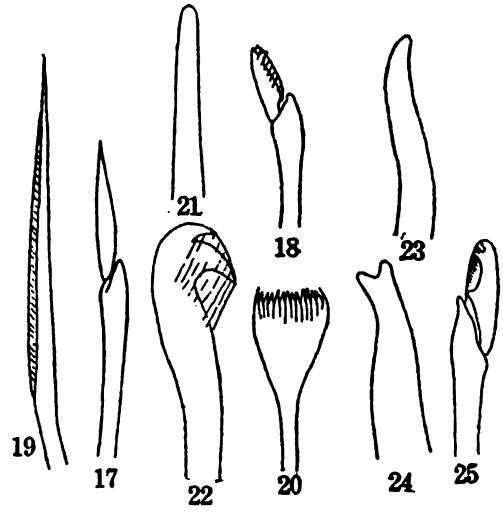
One entire specimen collected on rocks near Breaker Point, Pago Pago Harbor. It was in a tube which had a membranous foundation covered with débris, the tube having a general zig-zag outline with blindly ending branches. The tentacles and cirri

are long and sharp-pointed. There are no color characters to be noted. The animal is entire, is 25 mm. long, and its greatest width is 1.5 mm. There are about 110 somites.

The gills begin on setigerous somite 12 and extend to within about 10 somites of the pygidium. There is never more than one filament, which in most of the somites is quite similar in size and length to the dorsal cirrus. Toward the posterior end these filaments are shorter than the dorsal cirrus. In somite 50 (plate 3, fig. 4) the filament is also shorter than the dorsal cirrus, but a little stouter.

The prostomium (plate 3, fig. 1) is prominent, deeply incised, almost as long as the peristomium, but narrower. The tentacles are not quite twice as long as the prostomium, the longest barely reaching the anterior border of somite 4. The median and inner paired are almost of the same length, the outer paired are considerably shorter than these. They are all smooth and slender, with acute apices. There is a considerable distance between the bases of the median and the inner paired, so that a large part of the dorsal surface of the prostomium is uncovered. The eyes are inconspicuous.

The peristomium is on its dorsomedian line about as long as the three following somites, its lateral margins very nearly straight, the small lip on either side not very prominent. Somite 2 is very short, the boundaries between it and somites 1 and 3 being very indistinct. The nuchal cirri are slender, about half as long as the first somite.



TEXT-FIGURES 17 TO 25.

17 to 23. *Leodice tubicola.* 17, compound seta × 250; 18, compound seta × 250; 19, simple seta × 250; 20, pectinate seta × 500; 21, postero-dorsal acicula × 250; 22, postero-ventral acicula × 250; 23, anterior acicula × 250.

24 and 25. *Leodice aciculata.* 24, ventral acicula × 250; 25, compound seta × 250.

The tenth parapodium (plate 3, fig. 3) has a slender dorsal cirrus into which needle aciculæ extend, the setal lobe long, but with an unusually short dorso-ventral diameter. The anterior lip of the setal lobe is rounded; the posterior lip is a cirrus-like protrusion extending beyond the anterior. Between the two a large acicula with a bent apex comes to the surface and extends beyond the end of the posterior lip. Dorsal to the acicula is a tuft of simple setæ, 4 in number in the parapodium drawn; ventral to it a tuft composed of two kinds of compound seta. No pectinate setæ appear in the tenth parapodium, but they are in the eleventh. I am uncertain as to their exact distribution. Where there are so few of each kind of seta in a parapodium it is not possible to be sure that non-appearance may not be due to accidental loss and exact data concerning their distribution seems impossible to procure, if indeed it is a matter of any especial importance. The ventral cirrus is short, acute on the apex, and carried on the end of a pad-like swelling.

The fiftieth parapodium (plate 3, fig. 4) has a conical setal portion, the slender dorsal cirrus arising from a common base with the gill, which is a little shorter than the cirrus but stouter. The ventral cirrus is finger-shaped. I could find no needle aciculæ in the dorsal cirrus. The most noticeable feature of this parapodium is the very large

ventral acicula with sharply hooked apex, which comes to the surface near the setæ tuft. The single dorsal acicula is straight and bluntly rounded at the end. Dorsally in the parapodium drawn are 3 pectinate setæ with very long shafts and a tuft of simple setæ with very much curved stalks. Ventrally is a single compound seta of the usual type. The posterior parapodia retain the long dorsal cirrus found in the anterior somites and apparently do not differ essentially from the fiftieth. As the animal was allowed to remain in its tube, the posterior end was not well preserved, and it is difficult to be certain about the details of the last parapodia.

There are two pairs of anal cirri (plate 3, fig. 2), the dorsal pair much longer than the other.

Leodice tubicola has the three kinds of setæ characteristic of this genus, but differs from the majority in that there are two kinds of compound setæ. In the anterior somites both sorts appear. One (text-fig. 17) has a terminal joint shaped like a knife-blade, with perfectly smooth edges; the other (text-fig. 18) has the bidentate terminal joint which is more characteristic of *Leodice*. As stated above, the number of these setæ is so small in any somite that accidental loss might easily remove all of any one kind, and thus the result of accident be interpreted as absence, so that I have not attempted to study their distribution or to determine how far posteriorly the first kind of compound setæ extend. They are certainly absent on the fiftieth parapodium.

The simple setæ (text-fig. 19) are long and in the posterior somites are much more curved than in the anterior, but in other respects they are similar throughout the body. Each widens toward the end and tapers to a sharp point with a wing along one margin. The pectinate (text-fig. 20) have about 12 rather prominent teeth. In posterior somites their shafts are much longer than in the anterior.

The aciculæ from anterior somites (text-fig. 23) are slightly curved at the end, bluntly rounded. In posterior somites there are two kinds of aciculæ. The dorsal ones (text-fig. 21) are straight, with rounded ends, the ventral ones much larger (text-fig. 22), their apices bidentate, the subterminal tooth in each being especially large and sharp. The apex of each of this last form is covered by a hood. The position assumed by the ventral acicula is unusual in that instead of lying at an angle with the dorsal one the two are parallel, the ventral one coming to the surface near the middle of the setal lobe (plate 3, fig. 4).

The maxilla is light brown, with apices of forceps and toothed margins of plates darker. There is a dark-brown band at the junction between the carrier and each half of the forceps; along the line of junction between the two halves of the carrier and at the base of the carrier, which is prolonged into two dark-colored tooth-like processes (plate 3, fig. 5). The proximal plate on either side has 3 teeth, the right distal paired has 8, the left distal paired has 2, the unpaired has 8. Distal to each series of paired plates is a patch of pigment and a thin plate with a recurved corner. The mandible was broken in removing and only one half is drawn. This (plate 3, fig. 6) has a small beveled surface not very sharply marked off from the shaft and carries at one side a horn-like protrusion. The shaft is noticeably marked with concentric lines.

Crossland (1904, pp. 303–310, plate 21, figs. 1 to 8, text-figs. 52–55) described *Eunice* (*Leodice*) *tubifex* from Zanzibar, which is similar to *L. tubicola* in character of tube and in the possession of two kinds of compound setæ. While Crossland does not give measurements, this species was evidently much larger than *L. tubicola* and differs from it in nearly every respect. With these larger specimens of *Eunice* (*Leodice*) *tubifex*, Crossland collected some smaller individuals which he regards as the young of the same species. These he says were about one-third the size of the full-grown ones, one of "head" and 50 somites measuring 35 mm. in length; another of "head" and 35 somites was 13 mm. long.

While these are larger than my single specimen of *L. tubicola*, they agree with it so closely in the character of jaws and setæ (the only characters Crossland gives) that I regard them as belonging to the same species, and either my *L. tubicola* is a young

Eunice (*Leodice*) *tubifex* or Crossland's small specimens are not *tubifex*, and I would adopt the latter explanation. It is evident that a comparison of Crossland's figure 7, plate 21, with his text-figure 53, showing the jaw of the small and the large individual respectively, indicates that they belong to distinct species. Figure 7 shows the proximal paired plates of the small animal. Crossland in the text gives the formula for these as 4–4, but it seems to me that the figure shows 2 teeth on the right and 3 on the left, all teeth very large, while his text-figure 53 shows these plates to have 7 on the left and 6 on the right, all teeth very small. The forms of the carriers are also quite unlike. Having made a considerable number of comparisons of the young and adult jaws in other species of *Leodice*, and having found that the general form is usually quite the same, I am very doubtful if such a jaw as is figured in figure 7 could ever become transformed into that of text-figure 53. Again, a comparison of Crossland's figures 8*a* to 8*e*, showing the setæ and aciculæ of the small, with his figures 6*a* to 6*d*, showing the same structures in the large, shows very decided differences between the two. On the other hand, the figures of the small animals referred to above agree quite closely with the figures I have given of *L. tubicola*. The most important differences are that I could not find marginal striations along the edge of the unusual form of compound setæ, that the structure of the carrier and forceps as given in his figure 7 do not agree with mine, and that his text-figure 55 shows a gill with 4 branches, while in *tubicola* I never found more than 1 filament. Points of agreement are the form of the mandible and the general arrangement of the maxilla (Crossland's figure of the distal plates is not clear, but he gives 8–8 as the formula for their teeth); the form of the setæ and of the aciculæ, especially the large hooked ventral acicula, which is exactly like that of *tubicola*. Crossland states that some of these small animals were sexually mature, which he interprets as meaning that sexual maturity appears before the animal has reached the adult structural condition. I would regard it as an adult condition, and until better evidence is presented for their distinction will include the small specimens of *tubifex* with *tubicola*.

The type is in the American Museum of Natural History.

Leodice coccinea Grube.

Eunice coccinea Grube, 1878, pp. 153–155, pl. 9, fig. 1.
Eunice coccinea Crossland, 1904, pp. 297–303, pl. 20, figs. 6 and 7, text-figs. 46 to 51.

In life the whole anterior end is dark green and very iridescent, the prostomium a little lighter green than the peristomium, the tentacles a lighter green than either. The tentacles have more or less purplish pigment around their bases and are a lighter green than the prostomium and have uncolored apices. The nuchal and dorsal cirri are colorless, except for a faint greenish band around the middle. The anterior somites are dark green, but at about the region of somite 30 the color begins to lighten and posterior to this the green is soon lost, the body-color being a light brown with numerous small yellow spots. The whole posterior region of the body is light yellowish brown, still with the yellow spots, but at the extreme posterior end a purplish tint appears which becomes most intense at the pygidium. There is one pair of anal cirri which are rather stout and colored an intense purple, but with uncolored tips.

In the preserved material the bases of the cirrophores of the tentacles and a narrow ring around the base of each tentacle are dark purple, the tentacles and anterior cirri are green with uncolored tips, while later cirri are uncolored. The third setigerous somite is much lighter in color than any of the others. The peristomium is very distinctly marked dorsally by anastomosing longitudinally arranged purplish lines, and this is continued but very faintly over the succeeding 2 or 3 somites. The quasi-articular condition of the tentacles mentioned by Grube is shown only by wrinkles.

The single specimen in my collection does not agree with Grube's figure 1, plate 9, in that it has much shorter tentacles, the prostomium is more decidedly bifid and the third setigerous somite is uncolored. Grube states, however, that an African specimen

had the whole sixth somite (fourth setigerous?) uncolored, so he evidently found some variations in this respect. Crossland's material was largely from the Maldives and evidently showed a considerable range of variability in form and color, for he identified the species as *coccinea*, although some individuals showed as great a difference from Grube's description as does my Samoan specimen. Since the Samoan material agrees with Crossland's description, I have identified it as of this species.

A single specimen was collected on Aua Reef in Pago Pago Harbor, Samoa. The body is 230 mm. long and has a peristomial width of 3 mm. The gills begin on somite 6 and extend over a distance of 40 mm. There are approximately 300 somites.

Leodice aciculata, new species.

Plate 3, figures 7 to 13; text-figures 24, 25.

The general body-color is yellowish brown, somewhat lighter on the ventral surface, but otherwise with no noticeable difference in the two areas. Numerous small yellow spots are scattered over the entire dorsal surface. Toward the posterior end the general color becomes lighter, with a decided pearly luster which is more prominent on the ventral surface. A characteristic feature is an irregular banding and blotching of the tentacles and cirri with a brown pigment. On the tentacles there are several (5 or 6) of these bands which seem to extend entirely around, with many other shorter patches, which are very irregularly arranged. In alcoholic material the banding on the tentacles remains, but that on the nuchal and dorsal cirri may disappear. The pygidium and somites immediately in front of it have a decided purple color in alcohol. Irregularly distributed colorless patches occur on the dorsal surface, these patches being of various sizes. The fourth setigerous somite has a colorless dorsal band, which varies in width in different individuals. The ventral surface of the prostomium and peristomium are colorless, this appearing in a dorsal view as a whitish margin.

A specimen 190 mm. long has about 250 somites and a peristomial width of 3 mm.

The prostomium (plate 3, fig. 7) is 2-lobed, narrower than the peristomium. The tentacles are rather short and thick, the median extending as far as the second somite, the inner paired about as long as this, the outer paired shorter. The large eyes are in the usual position. As stated above, the tentacles are banded with brown, with the apices uncolored. The peristomium has straight margins, broadening at the anterior end, forming rather a prominent lip. The distinction between the first and second somites is most noticeable on the dorsal surface and is obscure elsewhere. The nuchal cirri are situated at the very anterior end of somite 2 and extend only to a little over half the length of the peristomium. They are slender and in life are banded with brown. Somite 3 is about as long as somite 2 and there is very little change in diameter until the extreme posterior end.

The apices of all parapodia are uncolored. The first has a very large dorsal cirrus, into which extend two aciculæ which are unusually large as compared with the needle-like aciculæ usually found in this position. The ventral cirrus is thick and heavy, the setal portion very small.

The tenth parapodium (plate 3, fig. 10) has a much greater dorso-ventral diameter, the dorsal cirrus smaller than in the first and provided with three aciculæ. The setal portion has a presetal and postsetal lobe, the latter the longer, and the aciculæ come to the surface between them. The ventral cirrus is also smaller than in the first parapodium, but is carried on the end of a rounded swelling, which gives it the general appearance of being larger.

A gilled parapodium (plate 3, fig. 13 of the sixtieth) shows a still greater reduction of the cirri, the setal portion remaining about as before. Two relatively large aciculæ extend into the dorsal cirrus, and two especially large ones occur in the setal portion. Toward the posterior end the parapodia (fig. 9, the twentieth from the pygidium) are more nearly conical, the distinction between the anterior and posterior setal lips is less marked, and the cirri are very small. There is one pair of stout anal cirri (plate 3,

fig. 8). The gills begin from the fourteenth to the twentieth setigerous somite. In one individual there was a 2-branched gill on the left side of the seventh and no more until the twenty-first, but this was exceptional. They arise as a single branch, but become more complicated in the immediately following somites. One individual had a 2-branched gill on setigerous somite 18, a 4-branched one on 19, and a 3-branched one on 20. Throughout the greater part of the body the gills have 5 branches, the number becoming reduced to 1 or 2 toward the posterior end, but they are relatively long. The last gill is not more than 20 somites from the pygidium. The gills (plate 3, figs. 9 and 13) arise from the base of the dorsal cirrus and are large as compared with it. The blood-vessel is also prominent.

The pectinate setæ have a very slender stalk, the apex widening to form a broad and rather flat plate, carrying about 20 teeth. Proximal to each tooth is a small, highly refractile spot. The compound setæ (text-fig. 25) have a small terminal joint, with a hood whose margin is finely denticulated, the basal joint being rather large. The terminal joint has a blunt apical and a sharp-pointed subapical tooth. The simple setæ are very long and slender, tapering gradually to a sharp point, and with a narrow wing on either side.

As stated above, the aciculæ are unusually large, especially through the median region, as is shown in plate 3, figure 13. The dorsal one of the two has a bluntly rounded apex and the ventral one is bifid (text-fig. 24). The aciculæ of the dorsal cirrus are also unusually large.

The jaw apparatus is very dark brown in color. The maxilla (plate 3, fig. 11) has a very short carrier, the forceps being long and slender and not much curved. The right proximal plate has 4, the left 3 teeth. The right paired has 5, the left has 7, the unpaired has 4. The unpaired plate is unusually small. The mandible (plate 3, fig. 12), has slender shafts widely separated, the beveled surface nearly round in outline. On the beveled surface of the mandible and on the ends of the teeth of the maxilla is a whitish incrustation.

This species was first collected in rocks outside the entrance light in Suva Harbor, Fiji. The surface of the rocks is much channeled by boring echinoids, and in the ridges left between these channels, *L. aciculata* occurs in large numbers, being the most abundant Leodicid that I found in Fiji. It was later collected in Samoa, a few individuals occurring in the rocks in Pago Pago Harbor, but was more abundant in rocks from the reef at Aunuu Island. Only a very few, however, were collected in Samoa. In a collection of Hawaiian annelids sent me for identification in July 1921, by the U. S. National Museum, was a single specimen of this species labeled as collected at Waikiki Beach. It was larger than any others I had seen, measuring 350 mm. in length, but was poorly preserved, so that this is only an approximate measurement. The coloring is more intense than in those from Samoa (possibly owing to greater age) and the brown bands on the cirri persist after preservation.

The type is in the American Museum of Natural History.

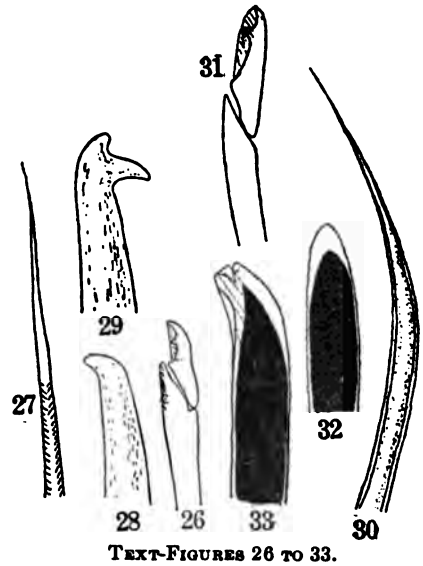
Leodice armillata, new species.

Plate 3, figures 14 to 19; text-figures 26 to 29.

The living animal is reddish brown, with the second setigerous somite uncolored and a row of white dots, one to each somite in the mid-dorsal line. The prostomium is colored like the remainder of the body, but has an uncolored patch on either side of the median tentacles. The tentacles are articulated, with greenish-brown pigment in the interarticular grooves, the median tentacles reaching as far as the fifth somite. The inner paired tentacles are almost as long as the median, the outer paired are much shorter. All dorsal cirri are uncolored; the anal cirri two pairs, one very short and colorless, the other pair much longer, colored light brown, but with uncolored tips. Neither is articulated.

In general appearance this species is very similar to *Leodice biformi-cirrata*, if individuals of the same size are compared, but differ decidedly from larger individuals of the latter species. In *L. biformi-cirrata* the cirri and gills are large relatively to the somite; in *L. armillata* behind the middle region the somites are short, thick, and much rounded, with relatively very short parapodia. In small *L. biformi-cirrata* gills are absent from a considerable number of the posterior somites and there is one pair of articulated anal cirri; in *L. armillata*, even in the small individuals, the gills are continued to within 10 somites of the pygidium and there are two pairs of non-articulated anal cirri (plate 3, fig. 15).

The prostomium (plate 3, fig. 14) is bilobed, rather narrower than the peristomium. The tentacles are all moniliform without evident cirrophores, with about 25 joints in the median, 18 in the inner paired, and not more than 10 in the outer paired. The relative lengths of these tentacles in preserved material is indicated in figure 14. The eyes are prominent and lie in the usual position. The anterior border of the peristomium is produced into a narrow collar-like structure which protrudes to a short distance over the prostomium. The width of the peristomium is about twice that of its length; toward its posterior dorsal surface it has a prominent white spot, the remainder of its surface being tinted light brown. The animal figured was 2 mm. wide at the peristomium, 60 mm. long., and had 160 somites. The second somite is about one-third as long as the first, its nuchal cirri without articulations and shorter than the peristomium.



TEXT-FIGURES 26 TO 33.

26 to 29. *Leodice armillata*. 26, compound seta × 185; 27, simple seta × 185; 28, dorsal acicula × 185; 29, ventral acicula × 185.

30 to 33. *Leodice crassi-tentaculata*. 30, simple seta × 250; 31, compound seta × 250; 32, dorsal acicula × 250; 33, ventral acicula × 250.

The gills begin with 1 filament on the sixth setigerous somite. On the left side of the body the eighth somite has a gill with 2 filaments, while on the right side the seventh and eighth each has 1 filament and the ninth has 3. Throughout the remainder of the anterior two-thirds of the body the number of filaments in each gill varies from 2 to 3. The number is reduced to 1 in the posterior one-third, not more than 10 of the terminal somites being without gills.

The tenth parapodium (plate 3, fig. 16) has a relatively small setal lobe with only a slight distinction between the anterior and posterior lips, while the ventral cirrus is supported on a swelling that is almost as large as the setal portion. The dorsal cirrus is long and slender, shaped much like the gill which rises at its base, the diameter of the gill being only a very little smaller than that of the cirrus. There are 2 straight aciculæ, and needle aciculæ appear in the dorsal cirrus. A posterior parapodium (plate 3, fig. 17) is small as compared with the vertical height of the somite. Each has a rounded post-setal lobe with two dorsal aciculæ and a ventral one, all nearly colorless or very faint yellowish brown. The dorsal aciculæ have curved apices, one more curved than the other (text-fig. 28), while the ventral one is bidentate (text-fig. 29).

The compound seta (text-fig. 26) has rather a stout basal shaft with a few indistinct denticulations along the longer edge. The terminal joint is small, the apex bidentate. There are only a few of these compound setæ in each somite and their basal portions

are long, extending beyond the end of the dorsal cirrus. The simple setæ are also long, slender, and sharp-pointed, extending beyond the cirrus, with lateral striations along two sides (text-fig. 27). There were only 4 of these in the parapodium drawn. A very small tuft of pectinate setæ lie close to the base of the simple ones; they are of the usual form but very small, with about 10 teeth.

A parapodium from farther forward in the body (the thirty-fifth) differed in no essential respects from the one just described, but had a larger number of compound and fewer of the other two kinds of setæ, and no ventral acicula.

The maxilla (plate 3, fig. 18) is colored brown, darker between the halves of the carrier; the base of the forceps, and the terminal portion of each half of the forceps. The teeth are very clear-cut and prominent. The proximal paired plates have 6 teeth on the right and 5 on the left, the right distal paired has 10, the left distal paired has 8 (the plate was rolled so that I was unable to get a clear view of its margin and this number may not be quite accurate); and the unpaired has 6. The mandible (plate 3, fig. 19) is rather more delicate than the maxilla, colorless except for a pigment patch between the halves and a line on either side near the margin of the beveled portion. From these colored spots concentric lines run inward over the surface. At the outer anterior angle of each side is a horn-like cylindrical extension of the plate, which has a peculiar whitish tint, and is quite unusual for this genus.

Leodice armillata was collected on Aua and on Utile reefs in Pago Pago Harbor. Samoa.

The type is in the American Museum of Natural History.

Leodice crassi-tentaculata, new species.

Plate 4, figures 1 to 5; text-figures 30 to 33.

A single specimen, collected on Utile reef in Pago Pago Harbor, in a loose coral rock lying on the sand near the shore. It has a general color-resemblance to *L. biformi-cirrata*, but can be distinguished from that species by the difference in the tentacles. While in *L. biformi-cirrata* the tentacles are articulated and not especially large, in *L. crassi-tentaculata* they are relatively enormous, being the largest as compared with the size of the entire animal that I have ever seen in this genus. The prostomial width of the specimen was 2 mm., the greatest body-width 3 mm. The specimen was in two pieces; the anterior piece 145 mm. in length with about 158 somites; the shorter piece had about 100 somites and was 60 mm. long. The extreme posterior end with pygidium was not found.

In preserved material the anterior somites are mottled dorsally with yellowish brown on pearly white; the sixth somite has more white than any other somite, and there is a brilliant iridescence. This color gradually weakens away from the anterior region, and disappears entirely behind somite 50, the remainder of the body being a dingy yellowish gray. Anteriorly the ventral surface is iridescent, but has none of the markings of the dorsal surface.

The gills first appear as a single filament on the left side of somite 34 and on the right side of somite 30. On the left side the second gill is 2-branched, while on the right it is the fifth which has the first of the 2-branched gills. This 2-branched condition is continued throughout the greater part of the specimen, but in the posterior portion of the smaller fragment there is but one branch. Gills continue to the very end of the specimen, losing, as above stated, in the posterior somites one of the gill filaments, but there is no diminution in the length of the remaining filament. The anterior gills are shorter than the dorsal cirri, but with the progressive decrease in the size of the cirri posteriorly and their own absolute increase in length, posterior ones are very much longer than the cirri.

The prostomium is deeply bilobed, each lobe subdivided incompletely into a dorsomedian and a ventro-lateral portion, forming the quadripartite lobing found in many Leodicids. The tentacles are very large, covering, when lying straight out in front,

the greater part of the dorsal surface of the prostomium (plate 4, fig. 1). The median tentacle is over 5 times as long as the peristomium, the inner paired more than half as long as the median, the outer paired about as long as the peristomium, all very thick and heavy. In the preserved material no tentacle shows any color. The eyes are prominent.

The lateral margins of the peristomium are nearly straight and parallel to one another, with the anterior lip on either side much in evidence. The peristomial length is about one-third less than its width and longer than the combined length of somites 2 and 3. In life the constriction between the anterior 3 somites is not very sharply defined and somite boundaries are further obscured by the dorsal mottling with pigment. The nuchal cirri are not quite as long as the peristomium.

Throughout the anterior region the dorsal cirri are especially prominent, being both long and thick. Behind the region of somite 20 they are more slender, but remain long, and in the gill region they become successively smaller beyond the region of somite 50. In the posterior portions they are shorter than the gills and are sharp-pointed.

As is common in this genus, the first parapodium has a small setal lobe with large cirri, though these latter are relatively smaller in *L. crassi-tentaculata* than in most species. The tenth parapodium (plate 4, fig. 2), has a prominent setal lobe with dense tufts of simple and compound setæ. The anterior lip is vertical, with a dorsal protrusion; the posterior lip is rounded. The apex of the setal portion has a ventro-anterior and a dorso-posterior rounded swelling. The compound setæ arise between the anterior lip and the former of these swellings, while the simple setæ arise between the latter and the posterior lip. Three heavy aciculæ reach the surface between the two swellings. The dorsal cirrus is long and symmetrically narrowed toward the apex, the ventral cirrus short and thick on a rounded swelling. A tuft of needle aciculæ extends into the base of the dorsal cirrus. The fiftieth parapodium (plate 4, fig. 3) is much smaller than the tenth, and has fewer setæ. There is one dorsal and one ventral acicula, the latter hooked at the apex. The figure shows the rounded post-setal lobe, the anterior one being vertical. The dorsal cirrus is slender and sharp-pointed, larger than the base of the gill which arises from the basal portion of the cirrus. At some distance from its point of origin the gill divides into two nearly equal branches. There is a tuft of needle aciculæ in the dorsal cirrus. The ventral cirrus is conical, on the end of a rounded swelling. Parapodia from the posterior end of the specimen in general outline and setal components are not noticeably different from the fiftieth, but the gill is 1-branched.

The simple setæ are of varying lengths, but in the tuft they are arranged so that the longest lie at the dorsal part of the tuft. Apart from length differences, they are all alike, each (text-fig. 30) curved and tapering to a sharp point at the apex with a wing along the concave and convex edges. The compound setæ (text-fig. 31) have their basal portions with no denticulations along the terminal edge, the terminal joints with terminal and subterminal teeth covered by a hood with smooth margin. The pectinate setæ are very few in number, even in the posterior somites where the number in other species frequently exceeds the number of the other kinds. Each pectinate seta is very slender and delicate, with about 20 terminal teeth, but these were very difficult to demonstrate.

The aciculæ from somite 50 are very black (except for their extreme tips), the dorsal ones with bluntly rounded tip (text-fig. 32), the ventral ones with 2 teeth, of which the ventralmost is slightly the larger (text-fig. 33).

The maxilla (plate 4, fig. 4), is dark-colored, especially at the ends of the forceps and the plates. The carrier is small, each half rounded on the margin; the forceps heavy relative to the carrier. The proximal paired plates have 4 teeth on the left and 5 on the right, the distal paired have 8 on the right and 5 on the left, the unpaired has 7. Dark pigment-patches lie just beyond the distal plates and a very thin plate with one corner bent lies on either side of them. The mandible (plate 4, fig. 5) was

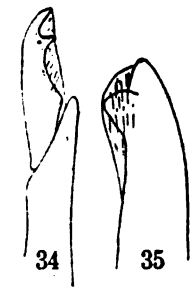
broken in removing and only one half is drawn. Each half is colorless except for faint lines along the line of contact of the two, and dark lines are at the median margin and outer angle of the beveled portion. From these patches of pigment concentric lines extend over the surface.

The type is in the American Museum of Natural History.

Leodice biformi-cirrata, new species.

Plate 4, figures 6 to 11; text-figures 34 and 35.

Collected both at Suva in Fiji and in Pago Pago Harbor, Samoa. A specimen from Samoa is about 95 mm. long and has a peristomial width of 2 mm. The body contains about 112 somites. The general body-color in life is an irregular splashing of white on a yellowish-brown background, the white being especially prominent on the anterior-dorsal face of the peristomium and on the fourth setigerous somite, which is entirely white, and a brownish dorso-median patch toward the posterior end. In some tentacles there is brown pigment in the constrictions between the joints. The tentacles are distinctly articulated with a small basal joint, the second joint being the longest of any, while at the apices they are moniliform. In a Suva specimen the median tentacle has 16 joints, the left inner paired one has 14, the right inner paired one has 11. It seems probable that accidental injuries are responsible for variations in this respect. The form of the peristomium and prostomium is indicated in figure 6, plate 4. The nuchal cirri are shorter than the peristomium and more or less wrinkled, but without articulations. The anal cirri are articulated (plate 6, fig. 7) and have brown pigment between the joints.



TEXT-FIGURES 34 AND 35.

Leodice biformi-cirrata. 34, compound seta × 185; 35, acicula × 185.

On one specimen the gills begin as a 2-branched organ on the fourth setigerous somite, become 4-branched on setigerous somite 5, 6-branched on setigerous somite 6, 7-branched on setigerous somite 8, and 6-branched on setigerous somite 12. From setigerous somites 15 to 20 the number varies between 5 and 6, but later decreases, the usual number being 3, though there are exceptionally 5. The last gill has one filament and is on the fifth parapodium in front of the pygidium.

The first parapodium has large cirri, but shows no especial characteristics. The tenth parapodium (plate 4, fig. 8) has a stout setal lobe with rounded posterior lip, 2 very heavy dark aciculæ which extend beyond the end of the posterior lip, and needle aciculæ in the dorsal cirrus. The dorsal cirrus is large and more or less wrinkled, but is not at all articulated, and a 4-branched gill arises near its base. Just inside the body-wall on the dorsal surface of the parapodium is a black pigment spot and there is a smaller brown one near the ventral surface. The dorsal spots can be seen in a surface view of the entire animal. The ventral cirrus is ovate on the end of a pad-like swelling. The thirty-fifth parapodium is very similar to the tenth in general appearance, but the ventral pad has disappeared and the ventral cirrus is much larger, extending to a considerable distance beyond the setal lobe. The dorsal cirri and gills are as in the tenth, but a ventral hooked acicula has made its appearance. In posterior somites the parapodia change very little in their general character, but the ventral pigment spot disappears and there is a gradual decrease in the number of gill branches.

The compound seta (text-fig. 34) has a heavy basal portion and a relatively small terminal joint, the latter with two large teeth. The simple setæ vary in length but all have clearly seen denticulations along one edge. Some are nearly straight, others are much longer and curved. The pectinate setæ are delicate with about 20 terminal teeth, the terminal one at one end being the longest.

The maxillæ are extremely delicate and were very easily broken, so that I was not able to get an entire one mounted for study. Figure 9 of plate 4 shows the right forceps

with the right proximal and distal paired plates, the former with 5, the latter with 8 teeth; figure 10 shows the left half of the forceps, the left proximal paired, and the unpaired plates. The proximal has 5 large teeth. The unpaired plate has 6 teeth. The forceps are slender and have very small carriers. It is not easy to understand how such delicate jaws as these could function in chewing and they may have been abnormal, though they are alike in all of the specimens I have. The mandibles have slender shafts which are darker and evidently much harder than the maxillary plates. They are dark brown, with the outer portion of the shaft next to the beveled portion lighter in tint. The beveled portion is covered by a whitish incrustation (plate 4, fig. 11).

The hooked acicula is heavy, with an especially large subterminal tooth (text-fig. 35).

This species shows some points of resemblance to *Leodice* (*Eunice*) *tentaculata* Quatrefages as described by Fauvel (1917, pp. 209–215, text-fig. 17), but differs in that the dorsal and nuchal cirri are not articulated, the number of filaments is much less, and the jaws have not the same structure.

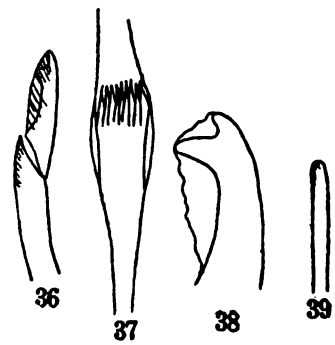
The type is in the American Museum of Natural History.

Leodice gracili-cirrata, new species.

Plate 5, figures 1 to 8; text-figures 36 to 38.

A slender, easily broken form, first found in loosely constructed tubes made of stones and shells and fastened to the under side of rocks in Suva Harbor, Fiji. Later they were found in cavities in the dead stag-horn coral, and in this latter locality were without definite tubes. The body of the living animal has a pearly luster with a good deal of iridescence, a pink tint anteriorly because of the blood, and the middle region decidedly purple. Toward the posterior end there is a large dark pigment spot on either side in each somite. The pygidium has pigment spots. The whole posterior portion may be colorless (except for the dark spots), in which case the pygidium is pink.

A specimen of average size measured after preservation 220 mm. in length, with a peristomial width of 2 mm., and this general width was maintained for the greater part of the body, but it tapered toward the pygidium.



TEXT-FIGURES 36 TO 39.

36 to 38. *Leodice gracili-cirrata*. 36, compound seta × 250; 37, pectinate seta × 250; 38, acicula × 250. 39, ventral acicula of *Marphysa simplex* × 250.

The prostomium (plate 5, fig. 1) is rather short and obscurely 4-lobed. The median tentacle extends to the posterior border of the fifth somite, the inner paired to the anterior border of somite 3, and the outer paired are a trifle shorter than the inner. In preserved material the median tentacle shows a slight trace of articulations, the inner paired are jointed for their terminal half, the outer paired for about the terminal third. The peristomium is as long as the three following somites, is noticeably narrowest along its anterior margin, its lateral margin decidedly rounded. Somite 2 is about one-third as long as somite 1, the nuchal cirri are long and slender, extending fully to half the length of the outer paired tentacles. The pygidium (plate 5, fig. 2) carries two pairs of anal cirri, the larger dorsal ones being stout at the base, but narrow rapidly and are very long; the ventral ones are very small and slender.

The tenth parapodium (plate 5, fig. 3) has a long dorsal cirrus which frequently has an appearance of jointing due to superficial wrinkling, and a broadly lanceolate ventral cirrus. Two aciculæ are in the setal lobe and there is a tuft of needle aciculæ in the dorsal cirrus. The fiftieth parapodium (plate 5, fig. 4) has a rounded post-setal lobe

with smooth aciculæ in the setal portion and needle aciculæ as before. The dorsal cirrus is long and slender, longer than the gills. The ventral cirrus is rather long, finger-shaped. A posterior parapodium (plate 5, fig. 5) has a setal lobe with a rounded outline and no elongated postsetal portion. The dorsal cirrus is very long and slender, the ventral one sharply pointed. There are 2 straight dorsal aciculæ and 2 ventral hooked ones. I could find no needle aciculæ. Inside the body-wall is a large black pigment spot just dorsal to the bases of the aciculæ.

The gills in one specimen begin as a single very long and slender filament on the third setigerous somite and the number of filaments increased to 2 on the fifth. Gills extend to about the region of the one-hundred and twenty-fifth from the pygidium. The largest number of filaments I could find in this specimen was 7. The dorsal cirrus has much the appearance of a gill filament, but is a little longer than any of the latter. The posterior gills are of but a single filament and very small.

The compound setæ (text-fig. 36) are similar throughout the body; the basal portions have narrow shafts much broadened at the apices, the terminal margins minutely serrated. The terminal joints have apical and subapical teeth, and a hood with minute marginal denticulations. The simple seta is long and slender, with a very slight increase in width toward the end and tapers gradually from this wider portion to the extremely acute tip. The pectinate seta (text-fig. 37) has the usual form with the terminal teeth the largest and about 9 other teeth along the edge.

The acicula (text-fig. 38) is heavy, with a large subapical and a smaller apical tooth, both covered by a hood.

The jaw apparatus varies in color with the size of the individual, being much darker in the larger and presumably older specimens. In the one figured (plate 5, fig. 6) the maxilla was light brown, with darker transverse bands on the base of the forceps. In a larger specimen the whole maxilla was one-third larger than the one figured and very much darker, the terminal two-thirds of the forceps being nearly black, and there was much dark pigment on the plates. In even the smallest specimens the shafts of the mandible are black (plate 5, fig. 7). The carrier of the maxilla is small, the terminal portions much curved. The right proximal paired plate has 7 teeth, the left one has 6, the right distal paired plate has 9, the left has 5, and the unpaired has 7. There is on either side a small rectangular plate lateral to the distal paired. The mandible has black shafts and a beveled portion which is not very sharply marked-off from the shaft. On either side is a thin chitinous plate with an irregular margin.

The type is in the American Museum of Natural History.

Genus MARPHYSA Savigny.

J. C. Savigny, 1820, Système des Annélides, p. 13.

Similar to *Leodice* in most characters, but without nuchal cirri.

Marphysa can always be distinguished from *Leodice* by the lack of nuchal cirri. Other characteristics, which are usually but not always present, are the relatively small size of the carriers of the maxilla, the presence of compound setæ with long terminal joints, at most only finely denticulated along one edge, instead of the toothed distal joint covered by a hood, which is found in *Leodice*. A frequent feature of *Marphysa* is also the pectinate setæ of the posterior end, which, instead of the fine teeth of those farther forward, have only a few very heavy ones.

Marphysa californica Moore.

Plate 4, figures 12 to 14; plate 6, figure 1.

Marphysa californica Moore, 1909, pp. 251 to 253, pl. 7, figs. 13 to 18; pl. 8, figs. 19, 20.

Collected in sandy mud outside of mangroves in a lagoon a short distance southwest of Nuuli. In life the prostomium is a little wider than the peristomium, and its dorsal surface is greenish in color, the margins uncolored. The peristomium and the first few somites are dark green, the peristomium dotted with minute white specks, but

posterior to the sixth to eighth somite the green color disappears and the whole body has a flesh-color due to the blood in the body-walls. The gills are bright red and are prominent in the living animal. In the preserved material all color is lost, and the whole body has a milk-white appearance, with much iridescence at the anterior end. The anterior end of the body is rounded in cross-section, posteriorly it becomes very flat, as is common in this genus.

An entire specimen after preservation is 160 mm. long, 1.5 mm. wide at the peristomium, and 3 mm. wide in the widest part. This is considerably smaller than Moore's type, but about the size of his cotype, assuming that his "3 mm." refers to the body-width.

The prostomium (plate 6, fig. 1) is laterally rounded and deeply bilobed, so that if the median constriction were deepened each half would form nearly a circle. The tentacles are slender, the unpaired the longest, the others successively shorter, but all at least twice the length of the prostomium. The eyes are very small, situated between the bases of the inner and outer paired tentacles. Moore's specimens lacked the posterior end. The pygidium of the Samoan specimen has 2 pairs of anal cirri, one pair much larger than the other, both situated ventral to the large oval anus (plate 4, fig. 12, ventral view).

The parapodia are as described by Moore. The setal lobe becomes more and more pointed toward the posterior somites and the ventral cirrus is very large and thick, fused to the setal lobe for the greater part of the length of the latter (plate 4, fig. 13). I found 4 aciculæ in anterior somites, 3 in the forty-fifth (plate 4, fig. 14), and 2 in the one-hundredth parapodium, which is essentially in agreement with Moore's description. The only lack of agreement is in the character of the ventral acicula, which comes to the surface just dorsal to the ventral cirrus. Moore did not find this in his type and in the cotype it is bifid and hooded. I find it present in all except the anterior parapodia, but its form is very unusual in that it is not bifid and hooded, but has a straight end, bluntly rounded at the apex, quite similar to the other aciculæ.

The gills in one specimen begin as 1 short filament on the twenty-fifth parapodium, on the twenty-sixth there are 3 very short filaments, and from here the number increases gradually to a maximum of 6. The filaments are slender and arise from a base which is very thick at the point of attachment and gradually narrows with the formation of each successive filament. The last gill has only one filament and is on the twentieth somite from the pygidium. The number of somites is approximately 300, so that gills extend over about 250 somites.

I can add nothing to the description Moore gave of the setæ or jaws except to make a slight change in nomenclature of the maxillary plates. Moore's figure 19, plate 8, is the left half of the maxilla (erroneously referred to in the text as the right). His III is the unpaired plate and his IV the left paired according to the nomenclature I am employing in this paper.

Marphysa macintoshi Crossland.

Marphysa macintoshi Crossland, 1903, pp. 137–138, pl. XIV, figs. 3 to 6; text-fig. 12.

A number of specimens collected in Suva Harbor, Fiji, which I have identified as belonging to this species because of the peculiar form of the undivided prostomium, the character of the jaw apparatus, and the general form of the parapodia. In the Fijian specimens the gills had fewer branches and the dorsal cirri were longer than indicated in Crossland's figure 6.

Marphysa simplex, new species.

Plate 5, figures 8 to 12; text-figure 39.

One specimen collected in Suva Harbor, in association with *M. macintoshi*, and much like it in general appearance, but differing decidedly in the form of the prostomium and tentacles. While in *macintoshi* the prostomium is shaped like a broad hoof of a horse, with no trace of a median indentation, in *M. simplex* (plate 5, fig. 8) it is

decidedly bifid. The tentacles of *simplex* are twice as long as the prostomium, while in *macintoshi* they hardly reach its anterior border.

The prostomium (plate 5, fig. 8) is about half as long as the peristomium and decidedly bifid, with a definite angle at the anterior and the outer posterior portion of each half. The tentacles are rather stout, smooth, tapering at the ends, the unpaired and inner paired ones nearly equal in length, the outer paired ones much shorter. In the preserved material their bases are colored much like the prostomium, but at the ends they are very dark brown, nearly black in color. No eyes are visible in the preserved material. The prostomium is about twice as long as the second somite; the two somites together are about as long as they are wide. There is no color in the anterior region, but the surface is very iridescent. This shades into a dirty gray posteriorly and toward the posterior end there is a faint trace of purple, due apparently to the tint of the intestine. Anteriorly the body is rounded, posteriorly it is much flattened.

The animal is 100 mm. long, with a peristomial width of 2 mm., a greatest body-width counting parapodia of 4 mm., and contains about 200 somites. It seems to be entire, but lacks anal cirri.

The gills begin as a single short filament on somite 242, the number increases to 2 on about somite 30 (plate 5, fig. 10) there is later an increase to 3, and throughout the greater portion of the gill region the number is 4 (plate 5, fig. 11). The last gill is on about the twentieth somite from the posterior end, the decrease in number of filaments being very abrupt at the end.

The parapodia are unusually uniform in size throughout the body. The tenth (plate 5, fig. 9) has a short anterior and a rounded posterior lip, with aciculæ protruding from between the lips. The ventral cirrus is rounded, the dorsal cirrus pointed at the apex. The forty-fifth parapodium does not show the distinction between anterior and posterior setal lips shown by the tenth, and the dorsal cirrus is narrower (plate 5, fig. 10). A bifid gill arises from the dorsal surface and there are 2 dorsal and 2 ventral aciculæ. A tuft of needle aciculæ extends into the dorsal cirrus. A posterior parapodium (plate 5, fig. 11) differs from the forty-fifth, mainly in the greater gill development. It has one dorsal and one ventral acicula and needle aciculæ in the dorsal cirrus. I could not find any of these needle aciculæ in the dorsal cirrus of the tenth parapodium.

The dorsal aciculæ are straight with rounded ends, while the ventral ones have the usual form, with a terminal and a subterminal tooth and a hood (text-fig. 39).

No compound setæ were to be found. The simple setæ are very long and slender, showing nowhere any indication of a broadening from the average width of the stalk, but tapering apically to a very slender point, the whole setæ thrown into several curves. Along one margin there may be a series of very small denticulations. The simple setæ are quite similar in form throughout the body, varying only in the number of curves, in length, and in the sharpness of the marginal denticulation.

Pectinate setæ occur sparingly in anterior somites, a parapodium from the region of somite 45 showing two, but I could find none in the parapodium drawn in figure 9. At the extreme posterior end they are more prominent. They are all of one kind, with a broad unsymmetrical end and about 25 very slender teeth.

The maxilla is dark brown in color. The whole jaw apparatus was broken in removing it from the body, and I am unable to give all of the details of its structure. The carriers are broken (plate 5, fig. 12). The forceps are long and not much curved, the left proximal plate has 5 teeth, and apparently the right one has 5 or 6. The right distal paired plate has 8 teeth, the left paired has 2, the unpaired has 9. The forceps are dark brown, the other plates much lighter in tint, but colored dark brown along the edge where the teeth are. The mandible was too badly broken to describe, so that aside from the statement that along the cutting edge and on the shaft there is much dark pigment I am unable to make any statements concerning it.

The type is in the American Museum of Natural History.

Genus PARAMARPHYSA Ehlers.

Ernst Ehlers, Florida Anneliden, p. 99.

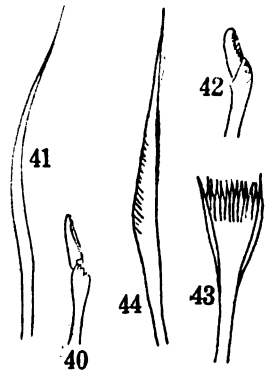
Similar to *Marphysa* in every respect except that it lacks gills. The individuals are usually small as compared with *Marphysa* and have delicate and comparatively soft jaw-apparatus.

Paramarphysa teres, new species.

Plate 6, figures 2 to 6; text-figures 40, 41.

Two incomplete specimens were collected in Pago Pago Harbor. One specimen, incomplete posteriorly, is 75 mm. long, 0.75 mm. in diameter at its widest part, and contains over 200 somites.

The prostomium (plate 6, fig. 2) is deeply bilobed, hardly wider than the peristomium. The median tentacle is about twice as long as the prostomium, the inner paired about half as long as the unpaired, the outer paired rather more than half as long as the inner paired. On either side there is a prominent eye situated just outside the base of the inner paired tentacle. No pigmentation is present in any portion of the body. In the preserved material the anterior ventral surface is much flattened, the parapodia prominent, and the dorsal cirri are relatively large. Behind about the region of somite 50 there is a change in the form of the body, in that the cross-section is nearly round and the dorsal cirrus becomes very small.



TEXT-FIGURES 40 TO 44.

40 and 41. *Paramarphysa teres.* 40, compound seta × 250; 41, simple seta × 250.

42 to 44. *Lysidice fusca.* 42, compound seta×250; 43, pectinate seta × 500; 44, simple seta × 250.

One of the two specimens was badly distorted as a result of drying and the prostomium of the other had been injured, so that neither was entirely normal, but neither showed any distinction between the first two somites, which together are longer than the prostomium. At the anterior border the prostomium has a median indentation, and its anterior diameter is a trifle wider than its posterior.

Anterior parapodia (a drawing of the thirteenth is shown in figure 3, plate 6) have relatively rather prominent dorsal cirri, with a vertical anterior and a rounded posterior lip, and a dense tuft of setæ arising between the two. There is a single acicula situated near the dorsal surface of the parapodium. The acicula has a very dark base, but is much lighter in color near the apex. Both simple and compound setæ were present in the parapodium drawn. A number were broken, but apparently the arrangement is that there is an anterior vertical row of compound setæ extending to the dorsal surface of the parapodium. Posterior to the dorsal end of this row is a smaller tuft of simple setæ. A posterior parapodium (plate, 6, fig. 4, from the region of the two-hundredth somite) is conical, with no evident distinction between anterior and posterior lips, and with quite similar dorsal and ventral cirri. The ventral cirrus is located a little nearer the apex of the parapodium than is the dorsal, but otherwise they are very similar. In the one drawn there were 2 simple and 2 compound setæ, the simple lying ventral to the compound. Simple setæ from the region of the two-hundredth parapodium are very slender, of uniform width to about one-third of their length outside the body-wall; at this point they bend at an angle of about 45° and taper to a very fine point. The compound setæ are very small and slender, the terminal portion having an apical and a subapical tooth and a hood (text-fig. 40). In the thirteenth parapodium the compound setæ are similar to those in later somites, while the simple ones widen slightly, bend toward the apex, becoming very narrow and curved beyond the bend (text-fig. 41).

In both of the specimens at my disposal the jaw apparatus was incomplete, apparently due to injury. The carrier is large, the forceps have heavy bases and slender apices, and the proximal paired plates each has 3 teeth. I could find no other plates (plate 6, fig. 5). The mandible is composed of slender halves rather widely separated (plate 6, fig. 6).

The type is in the American Museum of Natural History.

Genus ONUPHIS Audouin et Milne Edwards.

Audouin et Milne Edwards, 1834, p. 151, pl. 3A, figs. 1 to 5.

Prostomium with 7 appendages arranged in 3 rows, the anterior row of two "frontal tentacles" or "frontal palps," short and rounded at the ends. Other appendages on ringed cirrophores. Anterior parapodia produced so as to extend in front of the prostomium. The gills are pectinate or simple. With one pair of nuchal cirri.

Onuphis may be distinguished from *Diopatra* by the gills, which in the latter genus are spirally coiled, and from *Hyalinæcia* by the possession of nuchal cirri lacking in *Hyalinæcia*.

Onuphis holobranchiata v. Marenzeller.

Onuphis holobranchiata v. Marenzeller, 1879, p. 24–26, pl. 4, fig. 1.
Onuphis holobranchiata Crossland, 1903, p. 135, pl. 14, fig. 2.
Onuphis holobranchiata Augener, 1913, p. 283–284.

A single incomplete specimen lacking the posterior end was collected in Suva Harbor, Fiji. What remains of the body is 30 mm. long, 2 mm. in greatest width, and contains 69 somites. The color is a uniform dark brown, with brilliant iridescence on the dorsal anterior surface. In all details of surface structure this agrees closely with v. Marenzeller's description and figures. In the jaws there are only slight discrepancies, the carriers having more globular outlines than v. Marenzeller described.

Augener suggests that this species may be identical with Johnson's *Onuphis* (*Northia*) *elegans* and *iridescens* (1901, pp. 406 to 408, plates 8, 9, figs. 77 to 92). In gill structure *O. holobranchiata* agrees more closely with Johnson's species *elegans* than with *iridescens*. I have compared the Suva specimen with one of *O. elegans* which I collected at Friday Harbor, Washington. Neither has the 3-jointed inner paired tentacles figured by Johnson, but my Friday Harbor specimen agreed in other details, especially as to the jaws, with Johnson's description, and differed in jaw structure from the Suva specimen. I think they are distinct species, though closely related.

v. Marenzeller's specimens came from the east coast of Enosima Island, and Augener's from Sharks Bay, Freycinet, estuary between Baba Head and Cararong "Halb-Inseln," in 7 to 11 meters.

Genus LYSIDICE Savigny.

J. C. Savigny, Système des Annélides, 1820, p. 13.

With a jaw apparatus like that of *Leodice*, but with only 3 tentacles and no nuchal cirri. The mandible is usually very large as compared with the maxilla. Generally rather small in size.

Lysidice fusca, new species.

Plate 6, figures 7 to 13; text-figures 42 to 44.

Collected both at Suva in Fiji and at Pago Pago Harbor in Samoa. The animal lives in the porous rocks in association with *Nicidion*, and in Samoa is as abundant in the porous surface of the dead rock as is *Nicidion* in the West Indies. Because of the way it twists its body into the intricate cavities of the rock, unbroken specimens are difficult to secure.

There is considerable variability in both size and color. The specimen whose maxilla is drawn in figure 12 was 2 mm. in body diameter, and this would be about the maximum size. The most characteristic coloration is that figured (plate 6, fig. 7),

in which there is a sharply defined dark patch on the dorsal surface of the prostomium and the first 3 somites are dark brown with numerous white spots. Somites 4 and 5 are uncolored and the remainder of the body is like the anterior region, except that the colors are lighter. In most of the body each somite has a narrow darker band across its anterior margin. The pygidium (plate 6, fig. 8) is darker than is most of the body, with a narrow very dark band across the posterior margin of each somite. The third body somite may show less pigment than the first and second and there may be a little pigment on the fourth and fifth. Preserved material shows at best only a trace of this coloration and it may be entirely lost.

The prostomium (plate 6, fig. 7) is deeply bilobed and is wider than the peristomium. The tentacles are uncolored, the median one a little longer than the prostomium, the two lateral ones extend just beyond its anterior margin. The kidney-shaped eyes are very dark and prominent.

The first parapodium (plate 6, fig. 9) has a heavy ventral and a more slender dorsal cirrus; the tenth (plate 6, fig. 10) has a very large setal lobe and the ventral cirrus is on the end of a heavy pad-like structure; in posterior parapodia (plate 6, fig. 11) the setal lobe is conical and the ventral cirrus very small. In all parapodia the dorsal cirrus is slender. The anterior parapodia have each one large acicula, to which a ventral hooked acicula is added in later somites. There are no needle aciculæ in the dorsal cirri. There is one pair of stout anal cirri (plate 6, fig. 8).

The setæ are all very small. The tenth parapodium has a dense tuft of compound setæ, each with a shaft serrated at the apex; the terminal portion has a terminal and a subterminal tooth covered by a hood with serrated margin (text-fig. 42). The pectinate setæ are small, each with about 12 teeth (text-fig. 43). The simple setæ (text-fig. 44) are short, curved toward the ends, and with serrated convex margins. In the posterior parapodia the pectinate setæ are much larger than anteriorly and form a prominent dorsal tuft on the setal lobe, while the other setæ remain as in anterior somites.

The maxilla (plate 6, fig. 12) is dark brown in color, the color deepening toward the inner margins, though in the forceps the extreme margin is colorless. The carriers are conical, almost as long as the forceps. The basal portion of the forceps is about as long as the free fang. The right proximal paired plate has 3 teeth, the left has 4. The right distal paired has 5 teeth, the left has 2. The unpaired plate has 3 teeth. On either side is a small accessory plate. The mandible (plate 6, fig. 13) is relatively rather large, each half with a decidedly rolled edge which is darker than the remainder. (Note that it is drawn under about half the magnification of the maxilla.) Most of the mandible is light in color, but there are numerous dark bands (plate 6, fig. 13).

The type is in the American Museum of Natural History.

Lysidice parva, new species.

Plate 6, figures 14 to 17; text-figures 45, 46.

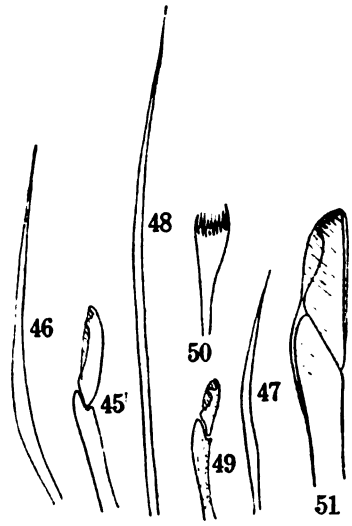
So far as my material goes, the animals of this species are of small size, the type, which was the only complete individual in my collection, being 70 mm. long and at no place more than 0.5 mm. in width. Other individuals were larger, but none more than 1 mm. in body-width. The anterior region of the living animal is colorless, except for faint indications of brownish spots on the parapodia on either side. Behind the colorless anterior region is one where there is a prominent dark spot on the dorsal surface of each parapodium. Farther back the body-color is lemon-yellow, due apparently to the intestine seen through the colorless body-wall. In preserved material the color is a uniform brown.

The prostomium (plate 6, fig. 14) is about as long as the peristomium and is bilobed, this lobing being more noticeable in some individuals than in others. The median tentacle is twice as long as the prostomium; the lateral ones extend for about one-third of their length beyond the prostomial border. The eyes are not very large, but are very distinct, dark brown in color. The peristomium is nearly twice as long as somite

2, the line of separation between the two being very indistinct. Later somites continue in general the diameter of the first two, with a narrowing and a flattening toward the posterior end, which carries one pair of rather heavy anal cirri.

Each anterior parapodium (plate 6, fig. 15) has a single acicula which is very dark brown in color except for the very apex, contained in a rounded setal lobe. The dorsal cirrus is long and slender, the ventral one much shorter. Posteriorly the only change in the parapodium is that the setal lobe becomes more pointed. The setæ are very small (note the scale of text-fig. 45); the simple ones broaden near the end and narrow to a very fine point (text-fig. 46); the compound ones have inconspicuous teeth on their hooded terminal joints (text-fig. 45).

The jaws are extremely small and very easily broken. The carrier (plate 6, fig. 16) is larger than the forceps, being broader and about of the same length. The forceps has slender fangs. Each proximal paired plate has lobings, hardly to be called teeth. I was unable to get satisfactory preparations of the distal plates, and beyond the statement that there are two on one side and one on the other I can say nothing of their structure. The whole maxilla is pale yellow in transmitted light, with a dark transverse band at the junction between carrier and forceps. The mandible is larger than the maxilla (note the difference in the scale of magnification in the drawings), and is very thin and delicate (plate 6, fig. 17).



TEXT-FIGURES 45 TO 51.

45 and 46. *Lysidice parva*. 45, compound seta × 560; 46, simple seta × 250.

47 to 50. *Nicidion fusca-fasciata*. 47, simple seta × 250; 48, simple seta × 250; 49, compound seta × 250; 50, pectinate seta × 250.

51. Compound seta of *Lumbrinereis sphærocephala* × 250.

In general form and in the structure of jaw and setæ this species is closely related to *Lysidice tortugæ* of the Gulf of Mexico (Treadwell, 1921*a*, p. 85, figs. 298 to 304).

The type is in the American Museum of Natural History.

Genus NICIDION Kinberg.

J. G. Kinberg, Annulata Nova, 1864, p. 564.

Similar to *Leodice* in having 5 tentacles and a pair of nuchal cirri, but without gills. The parapodial development, especially in the median and posterior regions, is very slight. They might be mistaken for young *Leodice* in which the gills have not appeared, but can be distinguished from these by the feeble parapodial structure.

Nicidion fusca-fasciata, new species.

Plate 7, figure 5; text-figures 47 to 50.

Collected near the Governor's wharf and on Aua Reef in Pago Pago Harbor, Samoa. The prostomium is entirely colorless, a little wider than the peristomium, and has a very shallow anterior median notch. The unpaired and the inner paired tentacles are yellowish brown in color, except for the extreme tips, which are without color. The outer paired are entirely colorless. The median tentacle is as long as the first 3 somites, the others from the inner to the outer become progressively shorter. The eyes are prominent. The peristomium is colorless and is longer than the two following somites. Somites 2 and 3 are entirely colored, except for a small white patch on either side of the mid-dorsal line on the anterior margin of each somite, and in somite

2 the small nuchal cirri, which are entirely colorless and very small, so that they look like two small white patches, one on either side of the somite. A very narrow band of the posterior margin of somite 3 is colorless. Somite 4 has on either side on the dorsal surface a triangular pigment patch with the apex pointed dorsally; somite 5 has a similar but larger patch and on somite 6 and 7 these patches from opposite sides have united in the mid-dorsal line. These are yellowish brown like those on somites 2 and 3, but are lighter in tint than on those somites. Behind somite 7 the pigment patch begins in front of the parapodium, bends around it so as to lie dorsal to it, and then extends dorsally to meet its fellow, leaving the posterior half of the dorsal surface of the somite uncolored. On either side is a colorless patch similar to those on somites 2 and 3. Behind the region of somite 20 these patches disappear and the band of pigment becomes entire, bifurcating at its ends so as to go on either side of the parapodium. The pigment disappears behind the region of somite 50, the posterior end being, so far as I can tell, without color.

The first parapodium has relatively very large dorsal and ventral cirri and a large acicula (plate 7, fig. 6). There is an antero-ventral and a postero-ventral setal lobe. The tenth parapodium (plate 7, fig. 7) has a slender dorsal and heavy ventral cirrus, 2 postsetal and one presetal lobes, and a single large acicula which is colorless at the base and end but dark in the middle region. A posterior parapodium (plate 7, fig. 8) consists mainly of a rounded setal lobe with very small dorsal and ventral cirri and 2 black aciculæ, the ventral one hooked at the end.

The simple setæ of the first parapodium are not very long, are very slightly widened toward the end, and very sharp (text-fig. 47). In later somites these setæ are much longer and not at all widened (text-fig. 48). The compound setæ are very small, with a minute terminal joint carrying a pointed terminal and a rounded subterminal tooth, the two covered by a hood (text-fig. 49). Anteriorly the pectinate setæ (text-fig. 50) are small, with about 12 teeth. Posteriorly they are larger and with more numerous teeth.

The pygidium was not present in any of my specimens.

The mandible (plate 7, fig. 9) is thin and only very faintly colored, except for dark bands at the base of the forceps and between the forceps and carrier. The carrier is small, the forceps long and not much curved; the right proximal plate has 6 teeth, the left has 5; the right distal paired plate has 9 teeth, the left has 4; the unpaired has 6. The mandibles (plate 7, fig. 10) are long and slender, the halves only slightly united, and have practically no pigment.

The type is in the American Museum of Natural History.

Subfamily LUMBRINEREINÆ.

Ventral cirrus absent, dorsal cirrus rudimentary or foliaceous. No appendages or evident gills, but with anal cirri. The maxillary plates are all paired, but the two of the same pair may or may not be symmetrical.

Dorsal lobes, probably functioning as gills, have been described in *Lumbrinereis branchiata* (Treadwell, 1921*a*, pp. 94, 95, plate 8, figs. 5, 6; text-figs. 333–343), but it is doubtful whether these could be regarded as homologous with the gills of the other Leodicidæ.

Genus LUMBRINEREIS de Blainville.

H. M. de Blainville, Dictionnaire des Sciences Naturelles, 1828, p. 46.

Body elongated, without prostomial appendages or parapodial cirri. The first somite interrupted ventrally by a forward extension of somite 2 to form the posterior border of the mouth. Maxilla of short carriers, forceps, and 3 pairs of toothed plates. Mandible about as long as maxilla, the two halves more or less fused. Setæ compound, simple, and hooked.

Lumbrinereis sphærocephala Schmarda.

Text-figure 51.

Notocirrus sphærocephala Schmarda, 1861, p. 116.
Lumbriconereis sphærocephala Ehlers, 1904, pp. 33–34, pl. v, figs. 3 to 11.
Lumbriconereis sphærocephala Augener, 1913, p. 288.

A single specimen was collected at low tide in Suva Harbor, Fiji. The living animal is more like *Oenone* than *Lumbrinereis* in its general appearance, for it has a soft body which secretes much mucus and it moves much more slowly than is usual in *Lumbrinereis*. In life the prostomium varies in form according to the degree of contraction, but is always nearly hemispherical. The greater part of the dorsal surface of the prostomium is colored dark greenish-brown, leaving only the margin uncolored. On the dorsal surface of the peristomium are two pigmented bands with sharply defined pigment rows lying in the broader one. Similar cross-bands appear in following somites, but gradually decrease in size posteriorly, so that behind the one-hundredth somite the dorsal surface of each somite is marked only by many minute spots of a golden color. The ventral surface has a yellowish tint, but no pigment. Intersegmental constrictions are uncolored. Preserved material as far back as somite 30 is reddish brown with darker bands in the middle of each somite, while behind this the whole animal has a decidedly greenish tint.

In the structure of the head region, the parapodia, and the jaws my specimen agrees with Ehlers's description, except that the prostomium is more rounded than is shown in Ehlers's figures 3 and 4. The teeth in the setæ are more sharply defined than Ehlers represents them (text-fig. 51), but this may have been merely an error made by his artist.

Ehlers's material was collected at Pitt's Island and Chatham Island; Schmarda's at Auckland, New Zealand; Augener's at Station 1, Sharks Bay, northwest of Middle Bluff, in 7 to 8 metres; Station 26, Sharks Bay, Sunday Island, 5.5 meters; Station 56, Koombaua Bay, 6 to 7 English miles southwest of Bunbury, 14.5 to 18 meters.

Benham (1915, p. 227) records a single specimen identified as of this species from east of Babel Island, Bass Strait.

Lumbriconereis brevicirra Schmarda.

Lumbriconereis brevicirra Schmarda, 1861, p. 117.
Lumbriconereis brevicirra Ehlers, 1904, pp. 35–36, pl. IV, figs. 13 to 20; pl. v, figs. 1 and 2.
Lumbriconereis brevicirra Augener, 1913, p. 288.

Two specimens were collected at Rat Passage, in Suva Harbor, Fiji, in sand at the bottom of a shallow pool on the surface of the reef at low tide. Later some were collected in mud near the Carnegie Library at Suva. In the preserved material the two from Rat Passage are uniformly dark gray in color, with only very faint pigment bands in some of the posterior somites. In life each had a median and two lateral pigment patches on both the dorsal and ventral prostomial surfaces. The median patches are circular in outline, the lateral ones are nearly linear. In the specimens from the mud the whole body-color is much lighter and the prostomial pigment patches are very prominent. In these latter specimens each somite throughout the body has a transverse reddish-orange pigment band, covering more than half of the dorsal and ventral surfaces. There are two pairs of anal cirri, one of which, in one specimen, was bifid.

The Fijian specimens agree with Ehlers's figures and description in the form of the prostomium and in the nearly complete fusion of somites 1 and 2. They all show more of the longitudinal plications on the ventral surface of somite 2 where it extends forward to form the boundary of the mouth than Ehlers shows in his figure 13, and I saw no trace of the everted nuchal organs Ehlers shows in his figure 14. The parapodia have longer posterior cirri than Ehlers describes, but the structure of setæ and aciculæ correspond with his description. In the jaw apparatus the maxilla is as Ehlers

describes it, but the mandible is quite different. Ehlers shows the mandible as constricted near the middle of the shaft, which widens at either end. My specimens have a mandible much more like that of *L. sphærocephala* as given in Ehlers's plate v, figure 11. This mandible which Ehlers figures is very different from anything which has been described for this genus, and it seems to me legitimate to question whether it was a normal specimen.

Schmarda recorded the species from Port Jackson; Ehlers from Chatham, Waitangi; Augener from Sharks Bay, 2 to 4.5 meters, Cockburn Sound, Port Royal, 14.5 to 18 meters, Albany, Princess Royal Harbor and Oyster Harbor.

Lumbrinereis japonica v. Marenzeller.

Plate 7, figures 1 to 4.

Lumbrinereis japonica v. Marenzeller, 1879, pp. 29–30, pl. v, figs. 3 to 3*d*.

Two specimens were collected in Pago Pago Harbor, on the under surface of loose coral rock at Utile reef. This is an unusual position for this genus, which is essentially mud-dwelling. The larger individual is 250 mm. long and composed of about 300 somites. The pygidial region is regenerating and contains about 15 very short and narrow somites. There are two pairs of short, stout, unequal anal cirri. v. Marenzeller's specimen lacked the posterior end. The second of my specimens is only about two-thirds as large as the other one, and only the anterior half is retained.

The prostomium (plate 7, fig. 1) is about as wide as it is long, with a blunt-pointed apex. The peristomium is a little wider than the prostomium, and is about twice as long as somite 2, from which it is separated by a poorly defined constriction. Ventrally, as is characteristic of this genus, somite 2 extends forward through an interruption in somite 1 to form the posterior border of the mouth. This ventral prolongation is longitudinally plicated.

The parapodia have prominent posterior lobes and, as stated by v. Marenzeller, each parapodium has a rudimentary dorsal cirrus into which a tuft of seta extends (plate 7, fig. 2, taken from somite 100). Posteriorly there is an increase in the length of the posterior parapodial lobes, but aside from this the parapodia are of the same form throughout.

The maxilla (plate 7, fig. 3) is dark brown, almost black, but with occasional lighter brown areas, especially along the margins of the carriers. The carrier is rather long and the margins have a frayed appearance. The forceps is slender. The left proximal plate has 4 teeth, the right proximal has 5. Apparently the 2 terminal teeth of the right plate are more or less broken. The second and third pairs of plates have respectively 2 teeth and 1 tooth on a side. In the figure these are shown as inverted, a position assumed during dissection. The teeth should lie on the inner side of each plate. The mandible (plate 7, fig. 4) is narrow at the base, but broadens at the anterior end. It is marked by concentric lines both in the shaft and in the beveled portion, the latter with very darkly pigmented ends.

v. Marenzeller gives no drawing of the prostomium, but his figures of parapodia and jaw agree so well with those of the Samoan specimens that I have no hesitation in assigning them to this species. v. Marenzeller figures three forms of setæ, simple winged, simple hooded, and compound hooded, the last two agreeing in form of apex and hood. In the smaller of my two specimens I find the form and distribution of setæ exactly as v. Marenzeller described them, but the larger specimen lacks the compound ones. It would be desirable to examine a series of varying sizes to determine if these setæ are lost with increasing age or size, but the material now in hand is not sufficient for this purpose.

Moore (1903, p. 454) records this species from Sagami and Suruga Bays, Japan. v. Marenzeller's was from the east coast of Eno-Sima Island.

Genus ARABELLA Grube.

A. E. Grube, Die Familien der Anneliden, etc., 1851, p. 45.

Body elongated, slender, without prostomial appendages or gills, with rudimentary dorsal and anal cirri. No compound, pectinate, or hooked setæ. Eyes often present on the prostomium. Maxilla with long slender carriers, forceps, and 4 or 5 pairs of toothed plates which may or may not be symmetrically arranged on the two sides. Mandible well developed, the shafts pointed and well separated. All jaw apparatus very dark in color.

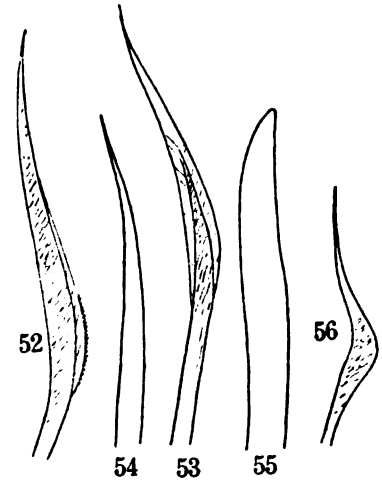
Arabella may easily be distinguished from *Lumbrinereis*, which it resembles very closely in general appearance, by the fact that the first somite forms the posterior border of the mouth, instead of the second, as in *Lumbrinereis*. In structure of the jaw *Arabella* resembles *Drilonereis*, but the maxillary plates are larger and may be more numerous, and the mandible is always more developed than in that genus.

Arabella dubia, new species.

Plate 7, figures 11, 12; plate 8, figures 8, 9; text-figure 52.

The type is from Pago Pago Harbor, Samoa, and is about 70 mm. long, with a prostomial width of less than 0.5 mm. An incomplete specimen found in mud in Suva Harbor, Fiji, is much larger but is badly preserved, so that measurements are of little value. It is possible that the type may be immature. The body is very iridescent. One preserved specimen from Pago Pago shows transverse brown bands on the somites, while the other is colorless.

The prostomium (plate 7, fig. 11) is elongated sugar-loaf in form, its length about one-third greater than its width. There are two pairs of eyes, the inner pair lying close together near the posterior border of the prostomium, and easily seen; the second pair are much less easily seen and lie one on either side, at a little more than half the distance from the corresponding inner eye to the prostomial border. The first somite is a little wider than the prostomium, but about two-thirds as long. Its anterior margin is noticeably recurved.



TEXT-FIGURES 52 TO 56.

52. Simple seta of *Arabella dubia* × 250.

53 to 55. *Drilonereis lumbricus*. 53, simple seta × 185; 54, acicula × 185; 55, acicula × 185.

56. Simple seta of *Drilonereis paucidentata* × 500.

The parapodia are well developed from the beginning. They have the form usual in this genus, with a rounded setal lobe and a finger-shaped posterior one. There is a single, rather prominent, yellow-colored acicula, rounded at the apex. The setæ (text-fig. 52) are broadened and bent toward the apex, this bent region striated. Along the convex margin is a narrow wing. A denticulation along the margin of the wing is very marked in some and barely discernible in others. The number of setæ in each somite is very small.

There are two pairs of stout anal cirri (plate 7, fig. 12). The maxilla is jet-black with long carriers, not all of which are shown in the figure (plate 8, fig. 8). On the basal portion of the right forceps are 7 prominent teeth, with smaller denticulations at the base. In the forceps figured, the right half has a bifid apex which apparently is not present in the other specimen at my disposal and is probably an individual

abnormality. The left half of the forceps has a shorter base and longer fang than the right; the base has 4 well-marked teeth. The first pair of plates are asymmetrical, the right one much shorter than the left, and its margin has 7 rounded teeth, while the left one is longer than the forceps, with at least 10 large, sharp teeth. The second, third, and fourth pairs of plates are symmetrical, the second and third each has 4 and 3 teeth respectively, while each one of the fourth pair has one tooth. The mandible (plate 8, fig. 9) is large as compared with the maxilla, its halves fused for more than half their length.

In character of prostomium, parapodia, and setæ this species is closely allied to *A. attenuata* Treadwell (1906, p. 1172, fig. 62), but differs in the character of the jaw. In the structure of the jaw it approaches more closely to *A. munda* Chamberlin (1919*b*, pp. 258-259), but differs in the number of teeth on the maxillary plates.

The type is in the American Museum of Natural History.

Genus DRILONERIES Clapérède.

E. Clapérède, Les Annelides Chætopodes, etc., 1870, p. 399.

Body elongated, slender, without prostomial appendages. Parapodia with rudimentary dorsal cirri, but frequently in anterior somites the parapodium reduced or practically absent. No compound or hooked setæ. Prostomium always very much flattened dorsoventrally, so that vertical diameter at the base is little greater than at apex. Maxilla with long, slender carriers, forceps, and three or four pairs of plates, the latter feebly developed as compared with *Arabella*. Mandible absent or rudimentary.

Drilonereis can usually be distinguished from *Arabella*, to which it bears a very close resemblance, by the peculiar flattened prostomium (see plate 7, fig. 14).

Drilonereis lumbricus, new species.

Plate 7, figures 13 to 15; plate 8, figure 10; text-figures 53 to 55.

Individuals of this species are large for the genus *Drilonereis*, measuring 150 mm. in length, with a prostomial width of 1 mm. and a body diameter of 2 mm. in the widest part. Apparently the diameter becomes smaller toward the posterior end, but the single specimen at my disposal was too badly preserved posteriorly to be certain on this point.

The prostomium (plate 7, fig. 13) has an oval outline as seen from above and is narrower at the posterior end, where it fits into the anterior margin of the peristomium. In preserved material the prostomium is bent ventrally so as to make an angle with the main axis of the body. On its median dorsal line is a relatively deep depression extending nearly the whole length of the prostomium. The peristomium is short on the dorsal surface, but extends forward on either side, so that the lateral length is more than double that of the dorsal. Ventrally it is thrown into a number of folds (plate 7, fig. 14). Near the posterior margin on the dorsal surface is a depression, the nuchal organ.

The anterior somites for about one-quarter of the whole body are smooth, highly iridescent, and greatly resemble an earthworm in general appearance. Behind this region the body-color is a dirty brown, but this may have been in part due to imperfect preservation. Apparently the pygidium is very narrow. The first setæ arise in a tuft on the side of somite 3, but the first appearance of anything that could be called a parapodium is on somite 30. Behind this region parapodia are clearly to be seen, but are never very prominent. Anteriorly each (plate 7, fig. 15) has a posterior lobe, a single stout acicula, and a tuft of simple bilimbate setæ curved at the end. Owing to poor preservation no satisfactory preparation of the parapodia could be obtained, and the figure from the forty-fifth somite is the best I could get. Farther posteriorly the acicula becomes relatively smaller, the shafts of the setæ elongate, the bilimbate

setæ become more numerous, and a second, smaller form of seta appears. In a posterior parapodia there are 6 of each form of seta. The bilimbate setæ (text-fig. 53) have long shafts, are noticeably curved toward the apices, with a striated wing which is wider on the convex side of the curve. It was not always possible to see this bilimbate structure, but this may have been due to the position the seta assumed in the preparation. The second form of seta (text-fig. 54) may have a base nearly or quite as broad as the bilimbate, but they narrow rapidly and terminate in a very slender sharp apex which barely protrudes from the surface of the setal lobe. The acicula is very large (plate 7, fig. 15, and text-fig. 55).

The jaw (plate 8, fig. 10) is jet-black. The carriers are long and slender, the forceps has a heavy basal portion with teeth on the inner margin of each half, the terminal portion strongly hooked. The proximal paired plates, each with four teeth, lie inside the curves of the forceps. There are two pairs of distal plates, each with one tooth. The mandible is represented by a pair of black plates lying in the wall of the pharynx considerably in front of the maxilla. There is a small plate attached to the ventral surface of the maxilla. This is really darker in color than is indicated in the figure, where it is shaded lightly so as to be more readily seen.

One specimen collected in Suva Harbor, Fiji.

The type is in the American Museum of Natural History.

Drilonereis paucidentata, new species.

Plate 7, figures 16, 17; plate 8, figure 11; text-figure 56.

Two individuals were collected, both very slender and very much elongated. One was found in Suva Harbor, Fiji, and one in Pago Pago Harbor, Samoa. The following description and figures are taken from the Samoan individual, which is incomplete but has about 450 somites. Its prostomial width is not over 0.25 mm. and the average somite length is 0.3 mm. I have designated as the type the specimen from Suva, which is nearly twice the size of this but also lacks the posterior end.

The prostomium (plate 7, fig. 16) is relatively rather large and is bluntly rounded. It is only a little narrower than the average body somite and is about as long as somite 1. As is characteristic of this genus, the prostomium does not, as in *Lumbrinereis*, thicken from the apex toward the base, but is of nearly uniform thickness throughout, the vertical diameter being about half that of the first somite (compare fig. 14 of *D. lumbricus*). In life the body has a yellowish tint which is most noticeable toward the anterior region, while posteriorly the intestinal contents give the body a gray tint. Preserved material shows a transverse brown band in the middle of each somite, but this is apparently due to coagulated blood and appears in so many of the Lumbrinereinæ as to have little diagnostic value.

The parapodia begin on somite 3 and are at first very small. They increase in size posteriorly but never become very prominent. Each has when fully developed a rounded setal lobe and a finger-shaped posterior lobe. Between the two on the ventral surface a heavy acicula protrudes to a considerable distance beyond the surface of the parapodium (plate 7, fig. 17). The setæ are all of the same kind, differing only in the length of the shafts. Toward the end each seta broadens and bends and narrows rapidly to an acute tip. There is little distinction to be made between a central shaft and a wing (text-fig. 56).

The jaws (plate 8, fig. 11) are jet-black. The maxilla has 2 long, slender carriers; the basal portion of the forceps is short and without teeth on the inner margins; the terminal portion is relatively large. Each proximal paired plate has 5 teeth, each of the second pair has 1 long and 2 short teeth, while each of the third pair has 1. A dark triangular plate is attached to the ventral face of the carrier, but I saw no mandible.

The type is in the American Museum of Natural History.

Genus OENONE Savigny.

J. C. Savigny, Système des Annélides, etc., 1820.

Prostomium with 3 short tentacles which may be covered by the anterior border of the peristomium. Two lobes of the dorsal surface of the peristomium may be protruded so as to cover the prostomium or be retracted into pits. Two pairs of prostomial eyes. The dorsal cirri are flattened plates. Maxilla with long, slender carriers and 2 series of toothed plates which may or may not be symmetrical on the two sides. Mandible short and broad. Setæ all simple, in a vertical row between the two lobes of the parapodium.

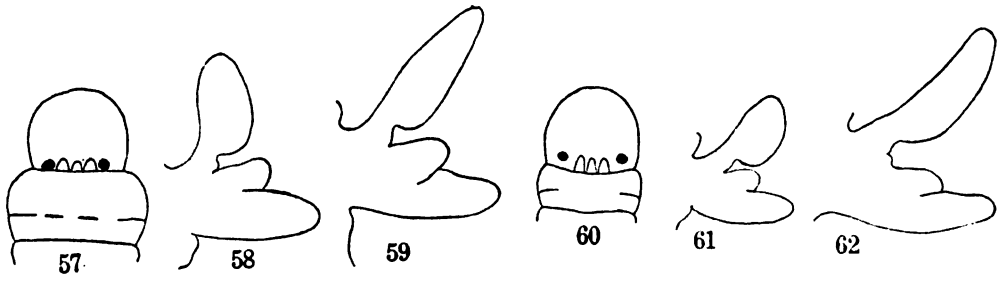
Oenone fulgida Savigny.

Text-figures 57 to 64.

Aglaura fulgida Savigny, 1820, p. 55, pl. 5, fig. 2.
Oenone lucida Savigny, 1820, p. 56, pl. 5, fig. 3.
Aglaurides fulgida Fauvel, 1917, p. 240–254, pl. 6, figs. 52 to 55.

For a diagnosis of the species and a full literature list see the paper by Fauvel.

Collected at Aua Reef and near the governor's wharf at Pago Pago Harbor, Samoa. The living animals are yellowish brown in color and very iridescent, but have no



TEXT-FIGURES 57 TO 62.

57 to 59. *Oenone fulgida* from Samoa. 57, anterior end × 5; 58, tenth parapodium × 5; 59, one-hundredth parapodium × 5.
60 to 62. *Oenone diphyllidia* from Tobago. 60, anterior end × 5; 61 tenth parapodium × 5; 62, one-hundredth parapodium × 5.

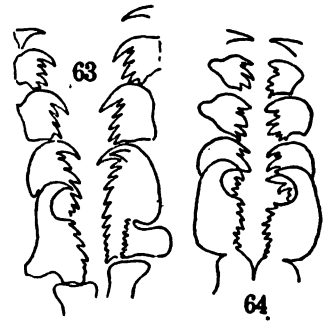
special pigment markings. They are very active in confinement and will crawl out of uncovered dishes. The prostomium is broadly rounded, with 3 tentacles and evertible nuchal organs which appear when the animal is moving. There are two pairs of eyes, the outer ones larger than the inner. After preservation the body-pigment turns to a brownish purple which is darker in some individuals than in others and in all cases is of a lighter tint ventrally than dorsally. In some cases in the preserved material this pigment completely obscures the eyes, while in others the smaller pair only are invisible. It seems probable that this condition is responsible for confusion in the classification of this and related species, some of which have been described as having only one pair or no eyes.

The peristomium is wider than the prostomium and usually is a little wider than the first setigerous somite. In some individuals there is a faint constriction, especially noticeable on the lateral and ventral areas, which obviously marks the boundary between the first and second somites. By a number of writers the possession of one or two apodous somites has been regarded as of importance in the separation of genera. If this distinction really occurs it would be important as indicating that the second apodous somite of one genus is homologous with the first setigerous of another. In my study of the Leodicidæ I have found so much variability between closely allied

species of the same genus in the degree of distinctness of the first two somites that I very much doubt whether there is anywhere a Leodicid with only one apodous somite. While this assertion is perhaps going beyond the evidence in such a genus as *Onuphis*, it seems to me obvious that these lateral and ventral markings in *Oenone* indicate clearly a fusion of somites and that a classification which separates this genus from others because of the (apparently) single apodous condition is erroneous.

The appearance of the ventral prostomial surface varies with the amount of protrusion of the palpal lobes, but it usually shows some longitudinal wrinklings. In other respects there is nothing to be added to the descriptions already given by Fauvel and others.

The genera of the Lumbrinereinæ with foliaceous dorsal cirri are somewhat confused, The first genera and species were described by Savigny (1820, pp. 55, 56, plate 5, figs. 2 and 3) as *Aglaura fulgida* and *Oenone lucida*. The type of the latter species and genus was afterward found to be an immature individual belonging to *Aglaura fulgida*, so that the latter was regarded as the valid genus and species. Ehlers (1864–1868, pp. 407, 408) showed that the name *Aglaura* was preoccupied and proposed instead the generic name *Aglaurides*. Savigny's original description of *Oenone* might be interpreted to read that the lack of tentacles was characteristic of the genus, and Ehlers redefined *Oenone* as having no tentacles and 1 apodous somite, while *Aglaurides* has 3 tentacles and 2 apodous somites. In other respects the two genera are alike. Fauvel (1917, pp. 240 to 257) accepts *Aglaurides* as the valid name, arguing that since *Oenone* was founded on an evident error it should disappear from the literature, and I followed this procedure in a paper on the West Indian Leodicidæ (Treadwell, 1921*a*, p. 116). In a personal letter Dr. Chamberlin pointed out that this procedure is contrary to the rules of nomenclature in that when *Aglaura* was discovered to have been preoccupied, *Oenone*, the oldest recorded synonym, should take its place. The criticism is valid and I have used *Oenone* accordingly.



TEXT-FIGURES 63 AND 64.

Jaws of *Oenone*. 63, jaw of *Oenone fulgida* from Samoa × 40; 64, jaw of *Oenone diphyllidia* from Tobago × 40.

Gravier (1900, p. 222) accepts *Aglaurides* as defined by Ehlers and retains *Oenone* to include species without antennæ or nuchal organs. Augener (1913, pp. 290, 291) and Chamberlin (1919*a*, p. 326) use *Oenone* as the only valid genus for this group, but neither writer seems to attach much importance to the tentacles and apparently they confuse the tentacles with the nuchal organs. Chamberlin (1919*a*, p. 337) speaks of "obscure antennal nodules—apparently subject to retraction like true antennal organs," and Augener (p. 290), in speaking of the "so genannten 3 Fuhler," says "Diese Fuhler sind ohne zweifel keine fuhlerartigen Anhange des Kopfes in gewohnlichen Sinne sondern als Nackenorgane aufzufassen." Chamberlin (1919*a*, p. 335, plate 62, figs. 2 to 5) describes as *Oenone telura* a species without tentacles, with peculiarly shaped somites around the mouth, and with a maxillary apparatus quite unlike any thus far figured in other species. Chamberlin states that the specimen had apparently been dried, which would lead to a distortion of the soft parts, and its resemblance in some details to *Oenone fulgida* would lead to a suspicion that the drying had been responsible for the apparent lack of tentacles. Dr. Chamberlin kindly offered to reexamine the specimen to be certain on this point, but it proved to be inaccessible and so the matter can not be determined. So far as I know, this is the only recorded case of an "*Oenone*" without tentacles, and since the presence or absence of tentacles

is obviously of generic importance, a new genus should be created for the reception of this species *telura*.

I have collected *Oenone* in Bermuda, Tobago, and the Dry Tortugas in the Atlantic and in Samoa in the Pacific. In a description of the West Indian species I suggested (Treadwell, 1921*a*, pp. 118, 119), that the species described by Ehlers (1887, pp. 109–111, plate 34, figs. 1–7) as *Oenone diphyllidia* of Schmarda (1861, p. 120, plate 32, fig. 256) was really *Oenone fulgida* Savigny, and that those of my own collections were *Aglaurides* (*Oenone*) *diphyllidia* Schmarda, which might be identical with *Aglaurides* (*Oenone*) *symmetrica* of Fauvel (Fauvel, 1917, p. 252). Augener (1913, p. 290), who apparently had access to Ehlers's collections, reported that he had identified as *Oenone fulgida* specimens from south Australia, and that a comparison of these with Ehlers's West Indian specimens showed that the two are identical. As will be noted immediately, the jaw structure is important in this connection, and it is perfectly possible that Augener did not examine this organ, but made his comparisons entirely from surface features.

I have made a careful comparison of my West Indian with my Samoan specimens and find that they agree in every respect except the form of the jaws. Text-figures 57, 58, and 59 are outline drawings of the anterior end, the tenth and the one-hundredth parapodium of the Samoan *Oenone*, while text-figures 60, 61, and 62 are corresponding drawings of specimens from Tobago in the West Indies. In other details, such as size, coloration, and habits, they are alike. It seems obvious that, *so far as these structures are concerned*, there are no differences of specific value between the animals from the two localities. Reexamination of my Bermuda material shows that the acicula I figured (Treadwell, 1921*a*, text-fig. 452) was not typical and that the aciculæ agree with those drawn in Fauvel's figure 52.

On the other hand, there are decided differences in the form of the jaw, as shown in text-figures 63 and 64. The jaw shown in text-figure 63 agrees in all essentials with Fauvel's description if due allowance is made for a slight difference in the position of the plates. In profile the teeth look large and sharp, but when rolled so as to be seen in full face they have the appearance shown by Fauvel, and in one specimen the second and third plates of the right-hand series had more teeth than here represented. The small plate adjoining the right-hand end of the carrier seems to me to be attached to the larger one and its teeth are to be seen only in strong reflected light, appearing then as bright spots.

My Samoan specimens are evidently *Oenone fulgida* Savigny, which is synonymous with *Oenone diphyllidia* Ehlers, while the ones I have seen from the West Indies are *O. diphyllidia* Schmarda. It seems probable that this latter species is synonymous with *O. symmetrica* Fauvel.

If my suggestion that all of the Leodicidæ have two apodous somites is correct, and if it be remembered that in *Oenone* either one or both pairs of eyes are not to be seen in preserved material, the distinction usually made between *Halla* and *Oenone* (see Gravier, 1900, p. 322, and Chamberlin, 1919*a*, p. 326) would appear of doubtful accuracy. I have examined a specimen bought of the Naples Zoological Station as *Halla parthenopeia* and two specimens identical with this belonging to the American Museum of Natural History but without data, and find that they are certainly the species described by Ehlers (1864–1868, p. 408, plate 17, figs. 25–34) as *Cirrobranchia parthenopeia*. A second pair of eyes apparently escaped Ehlers's attention and he does not mention the protrusible lobes which distinguish his genus *Aglaurides* from *Cirrobranchia*. Dissection of these specimens, however, shows the lobes lying under the peristomial border exactly as in *Oenone*. It seems probable that Ehlers really had a species of *Oenone* and probable that *Halla* was originally described from a member of this genus. The matter could, I suppose, be settled only by reference to the original type specimen, but I am skeptical as to the validity of *Halla*. *Cirrobranchia*, as Cham-

berlin and others have noted, is synonymous with *Halla*, which has precedence, if *Halla* is a valid genus.

Subfamily DORVILLEINÆ.

The characteristic genus of this family was named *Staurocephalus* by Grube (1855, p. 97), but Verrill (1900, pp. 647, 648) showed that the name was preoccupied and renamed it *Stauronereis*, making the subfamily Stauronereinæ. Chamberlin (1919*a*, pp. 338, 339) showed that *Stauronereis* was preoccupied by *Dorvillea*, given by Parfitt (1866, pp. 113, 114, with 5 figures) to a new genus *Dorvillea*. The name of the principal genus should then be *Dorvillea* and the subfamily renamed accordingly.

Chamberlin is in error in referring to a swarming like that of Palolo in *Dorvillea*. Mayer (1902) corrected an error in an earlier paper and pointed out that this swarming species is *Leodice fucata* Ehlers.

Genus DORVILLEA Parfitt.

Parfitt, E, 1866, Zoologist, 2d series, pp. 113, 114.

Prostomium rounded, pentagonal or quadrangular, with two more or less articulated tentacles and elongated palps which may be spirally contorted. Body with relatively few somites, parapodia with dorsal and ventral cirri but without gills. Four anal cirri. Maxilla of 2 or more rows of toothed plates on either side, the rows all united at the base but diverging in a V-shape. Mandible bifurcated, with slender shafts, the margin often prolonged laterally into rows of plates.

Dorvillea australiensis McIntosh.

Plate 8, figures 1 to 7; text-figures 65 to 68.

Staurocephalus australiensis McIntosh, 1885, pp. 232, 233, pl. 36, fig. 6; pl. 17A, figs. 9 and 10.
Staurocephalus australiensis Treadwell, 1906, p. 1173, figs. 63 to 66.

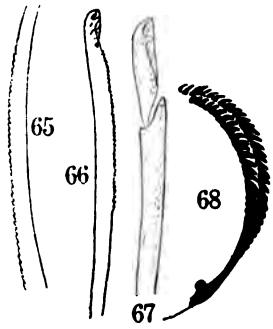
Dorvillea (*Staurocephalus*) *australiensis* was described by McIntosh from a posterior fragment of a single individual. Treadwell identified with this a species from Hawaii and figured the prostomium with appendages in which the tentacles are shown as unsegmented. Augener (1913, pp. 293–296) and Benham (1915, pp. 209–212, plates 41, figs. 58 to 66) described specimens of this genus from the Australian region as *S. australiensis*, though all of the tentacles in their specimens had strongly articulated tentacles. I have reexamined the Hawaiian specimen (now No. 5463 in the U. S. National Museum) and find that the tentacles certainly are not strongly articulated, though they show a jointing toward the end.

The only structures in which direct comparison is possible between McIntosh's and Benham's specimens are in the parapodia and setæ. The difference between the two figures of the parapodia (Benham, plate 41, fig. 62, and McIntosh, plate 36, fig. 6) might be due to imperfect preservation of the material or to the fact that they represent parapodia from different regions of the body, but this explanation does not hold for the setæ. Benham figures the terminal joints of the compound setæ as each having a stout subapical tooth and a denticulated margin to the hood, and he describes the simple setæ as "long, curved, capilliform" with fine serrations along the upper convex margin, while in McIntosh's figures (plate 17A, figs. 9, 10) the terminal joint of the compound seta has a small subapical tooth and no serration along the margin of the hood. The simple seta has a serrated edge and terminates in a bifid extremity.

In the form of the setal lobes and setæ Benham's specimens differ from the Hawaiian and the Samoan species. He states that the mandibles are without denticulations, while in the Samoan specimens they are denticulated (plate 8, fig. 7). The form of the paragnaths is quite unlike in the two cases. Augener's specimens from Australia had on the parapodia "am Ende 3 blatt-formige Lippen-eine vordere obere und eine

hintere mediane," while McIntosh's description of the type is that "superiorly the free edge of the foot presents two prominent mammillæ, between which the bristles of the region emerge." This is not in entire agreement with his figure, but is quite in accord with the conditions found in the Samoan and Hawaiian specimens and quite unlike those described by Augener. Augener followed Benham in his identification of his specimens with those of McIntosh and Treadwell, explaining the differences as due to poor preservation. It seems to me evident that the species described by Benham and Augener are not the same as the ones I have seen from Hawaii and Samoa, which I regard as belonging to McIntosh's species.

Several specimens were collected on Aua reef in Pago Pago Harbor in rocks near the upper end of the harbor and one on the reef at Aunuu. They are very sensitive to changes in the water and most of them died before they could be got to the laboratory. In the living animal the prostomium has a faint pink color on the anterior margin, but this fades out on the dorsal surface. The palps are colorless or only faintly tinted with pink. The peristomium is pink, this color being most intense along the posterior edges of the antero-lateral depressions and on the "caruncle." The first 6 somites show a pink color which is most intense along the anterior margins, but behind the region of somite 6 the pink color disappears and is replaced by a decided yellow. No color persists in the preserved material.



TEXT-FIGURES 65 TO 68.

Dorvillea australiensis. 65, dorsal simple seta × 250; 66, ventral hooded seta × 250; 67, compound seta × 250; 68, one half of maxilla × 12.5.

The prostomium is rounded (plate 8, fig. 1), not more than one-third the diameter of the peristomium. The palps are large, thick at the base, unjointed, and with rather blunt tips. The tentacles are less than half the diameter of the palps at the base and not more than three-quarters as long as they, and are jointed only toward the apices. There are two pairs of eyes—the dorsal ones the smaller, the larger ventral ones visible from the dorsal surface only through the translucent bases of the tentacles. Both pairs of eyes are very black. The peristomium is rectangular in outline, but with a deep depression on either side on the dorsal surface. The median ridge between these two depressions is continued forward to join with a knob which belongs to the prostomium, the whole forming a sort of caruncle.

The first parapodium (plate 8, fig. 2) has a rounded setal lobe, with lips equal in length. The dorsal cirrus is 2-jointed, the basal joint much the longer. The ventral cirrus is rather large, joined for about half its length to the setal lobe. There is a heavy acicula in the setal lobe and a tuft of needle setæ in the dorsal cirrus. There are two tufts of setæ, the dorsal ones simple and the ventral ones compound. In the tenth parapodium (plate 8, fig. 3) the parts are all larger, but the relative forms are about as before, except for an increase in the vertical diameter of the setal lobe. There are a dorsal and a ventral tuft of setæ with aciculæ as in the first parapodium. The pygidium is rounded, with one pair of long anal cirri (plate 8, fig. 4).

The dorsal setæ are long and curved, with minute denticulations along the convex margin and very small terminal teeth at the end (text-fig. 65). Ventral to these is a row of stouter setæ with serrated convex margin and apical and subapical teeth covered by a hood (text-fig. 66). Ventral to these are compound setæ having smooth basal joints; the terminal joints have each a large apical and a smaller subapical tooth, the whole covered by a hood (text-fig. 67).

The maxilla has the form characteristic of this genus, composed of two rows of plates on either side, with from 35 to 40 plates in each row, the rows from opposite

sides united in pairs by a V-shaped connection (text-fig. 68 shows one-half of the jaw). In the basal portion of each row the plates are closely united, looking like a series of vertebræ. At about the middle of the series (plate 8, fig. 6) the plates reach their greatest development. Each has a bifurcated base and a rather heavy fang. Along one edge of the fang is a plate-like protrusion with a row of teeth along its margin. In the view drawn the teeth appear as if on the margin of the fang, but in reality they are on a plate set at an angle to the fang and pointed away from the observer. At the apex of the row the plates become smaller and the teeth disappear (plate 8, fig. 5). The inner row is a little shorter than the outer. The mandible (plate 8, fig. 7) is black, each half with teeth along the anterior margin and small plates lateral to the apex. Apparently the number of these plates is not constant.

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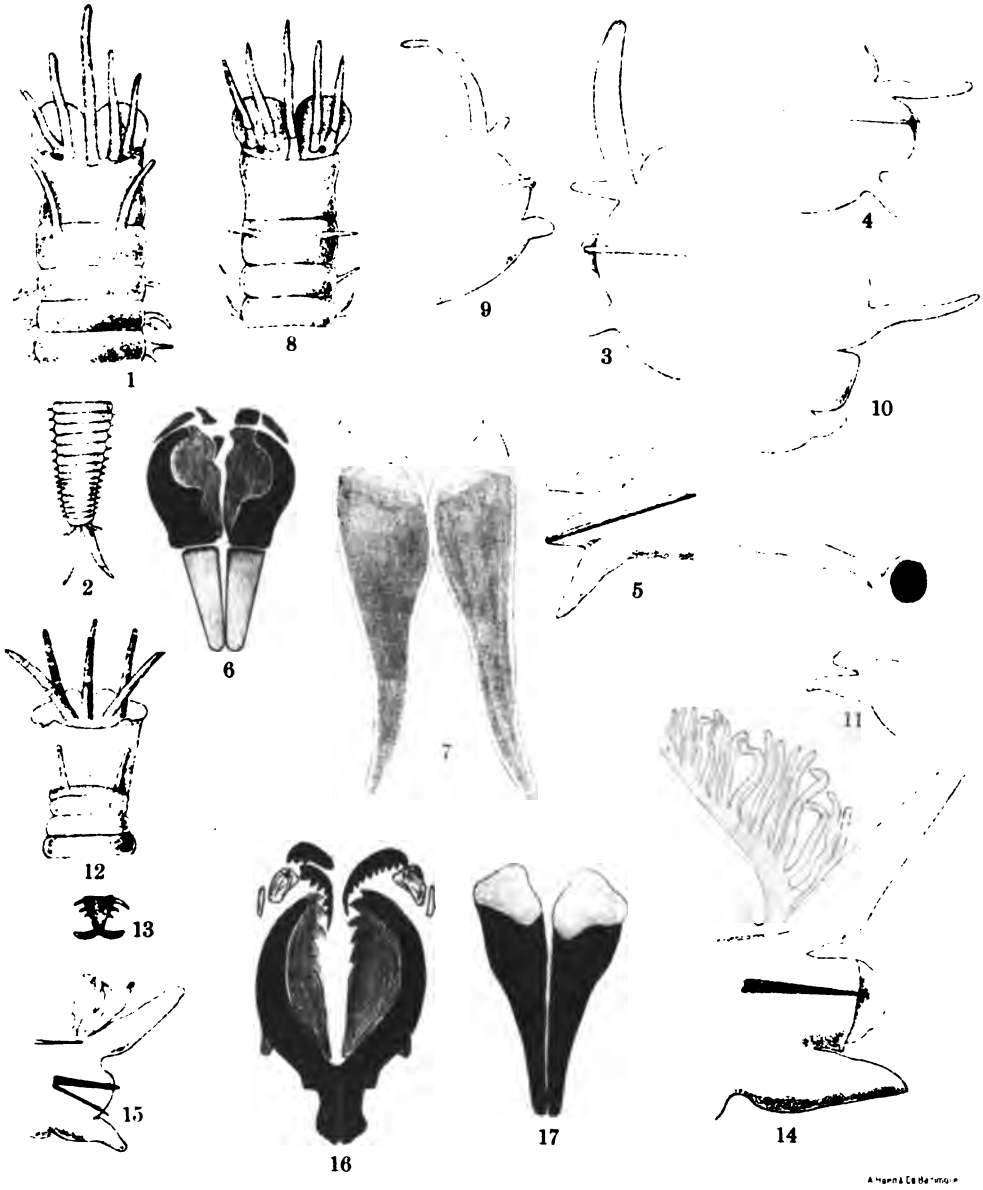
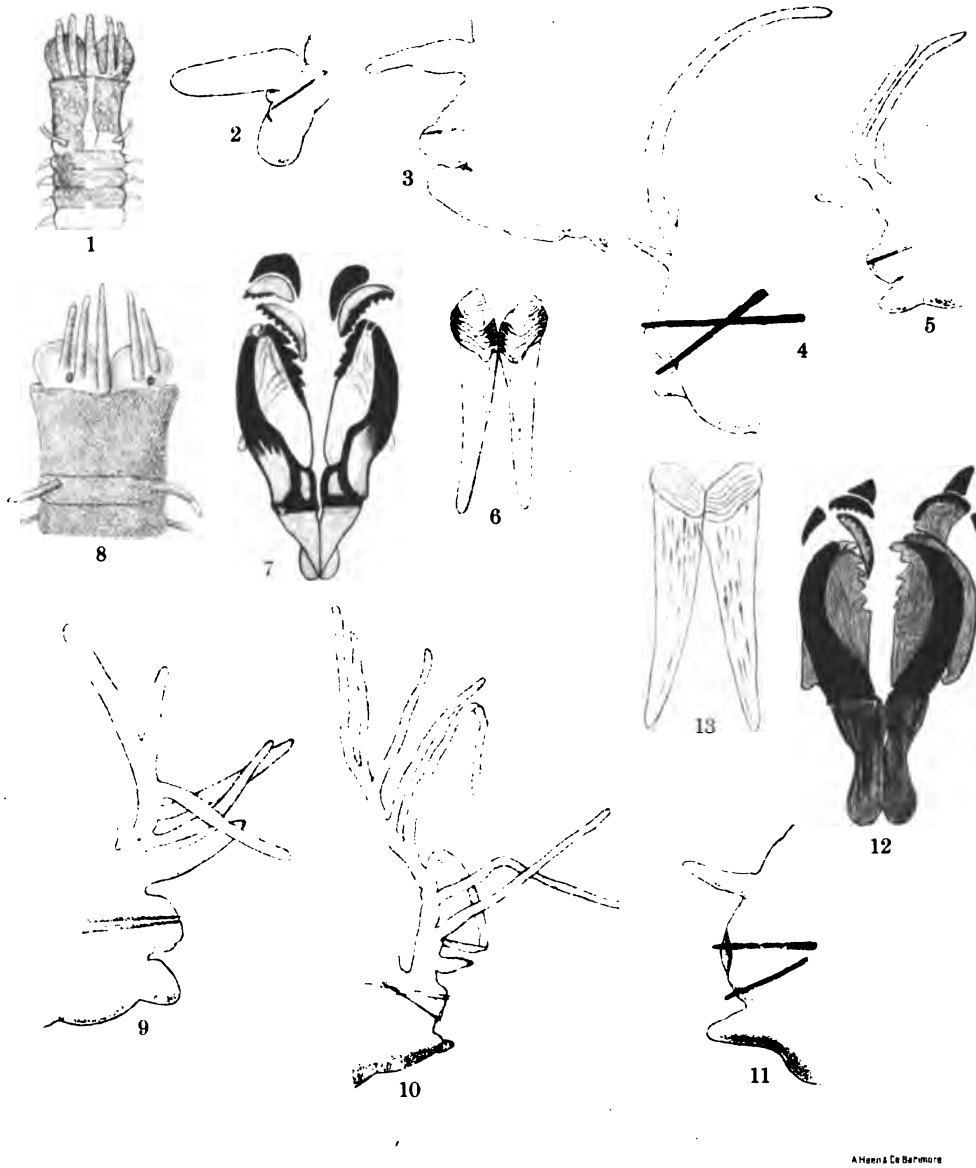


FIGURES 1 to 7, *Leodice viridis* Gray. Fig. 1, anterior end × 7.5. Fig. 2, pygidium × 7.5. Fig. 3, gilled parapodium × 22. Fig. 4, tenth parapodium × 27. Fig. 5, epitokous parapodium × 68. Fig. 6, maxilla × 15. Fig. 7, mandible × 15.

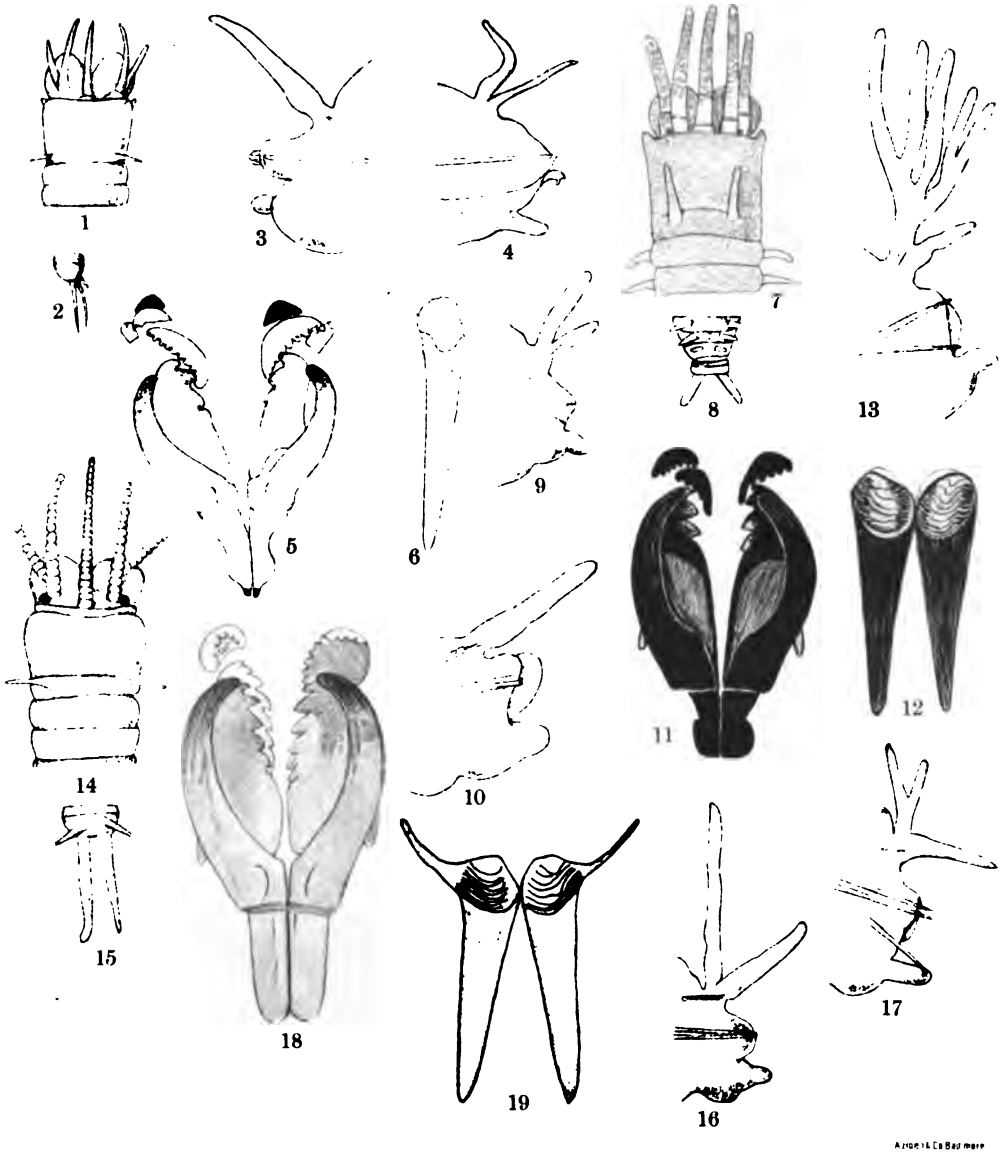
FIGURES 8 to 11, *Leodice viridis* Gray, variety *vernalis* Treadwell. Fig. 8, anterior end × 10. Fig. 9, gilled parapodium × 20. Fig. 10, ninth parapodium × 68. Fig 11, posterior parapodium × 55.

FIGURES 12 to 17. *Leodice aphroditois* Pallas. Fig. 12, anterior end × 2.5. Fig. 13, pygidium 2.5. Fig. 14, tenth parapodium × 15. Fig. 15, posterior parapodium × 15. Fig. 16, maxilla × 6.5. Fig. 17, mandible × 6.5.



FIGURES 1 to 7, *Leodice flava-punctata* Treadwell. Fig. 1, anterior end × 6. Fig. 2, first parapodium × 48. Fig. 3, eleventh parapodium × 48. Fig. 4, posterior parapodium × 48. Fig. 5, twenty-sixth parapodium × 23. Fig. 6, mandible × 20. Fig. 7, maxilla × 20.

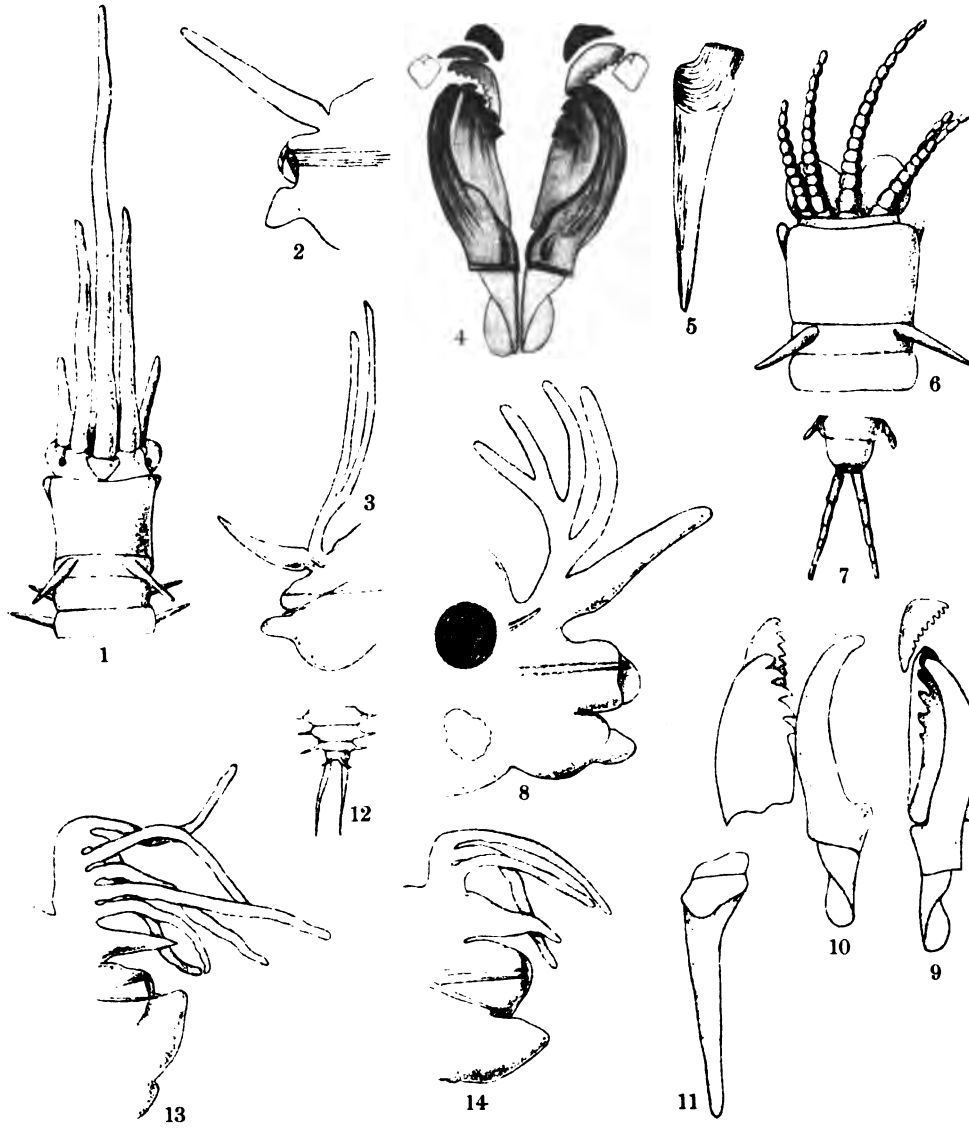
FIGURES 8 to 13, *Leodice suviensis* Treadwell. Fig. 8, anterior end × 6. Fig. 9, gilled parapodium × 11. Fig. 10, fiftieth parapodium × 8.5. Fig. 11, posterior parapodium × 23. Fig. 12, maxilla × 8. Fig. 13, mandible × 8.



FIGURES 1 to 6, *Leodice tubicola* Treadwell. Fig. 1, anterior end × 7.5. Fig. 2, pygidium × 7.5. Fig. 3, tenth parapodium × 35. Fig. 4, fiftieth parapodium × 35. Fig. 5, maxilla × 23. Fig. 6, mandible × 23.

FIGURES 7 to 13, *Leodice aciculata* Treadwell. Fig. 7, anterior end × 4. Fig. 8, pygidium × 4. Fig. 9, posterior parapodium × 23. Fig. 10, tenth parapodium × 23. Fig. 11, maxilla × 8. Fig. 12, mandible × 8. Fig. 13, sixtieth parapodium × 23.

FIGURES 14 to 19, *Leodice armillata* Treadwell. Fig. 14, anterior end × 13. Fig. 15, pygidium × 14. Fig. 16, tenth parapodium × 23. Fig. 17, posterior parapodium × 32. Fig. 18, maxilla × 23. Fig. 19, mandible × 23.



FIGURES 1 to 5, *Leodice crassi-tentaculata* Treadwell. Fig. 1, anterior end × 7.5. Fig. 2, tenth parapodium × 23. Fig. 3, fiftieth parapodium × 17. Fig. 4, maxilla × 15. Fig. 5, mandible × 15.

FIGURES 6 to 11. *Leodice biformi-cirrata* Treadwell. Fig. 6, anterior end × 4. Fig. 7, pygidium × 4. Fig. 8, tenth parapodium × 13. Fig. 9, right half of maxilla × 9. Fig. 10, left half of maxilla × 9. Fig. 11, half of mandible × 9.

FIGURES 12 to 14. *Marphysa californica* Moore. Fig. 12, pygidium × 7.5. Fig. 13, one-hundredth parapodium × 40. Fig. 14, forty-fifth parapodium × 40.

FIGURES 1 to 7, *Leodice gracilicirrata* Treadwell. Fig. 1, anterior end × 7.5. Fig. 2, pygidium × 7.5. Fig. 3, tenth parapodium × 20. Fig. 4, fiftieth parapodium × 13. Fig. 5, posterior parapodium × 20. Fig. 6, maxilla × 22. Fig. 7, mandible × 22.

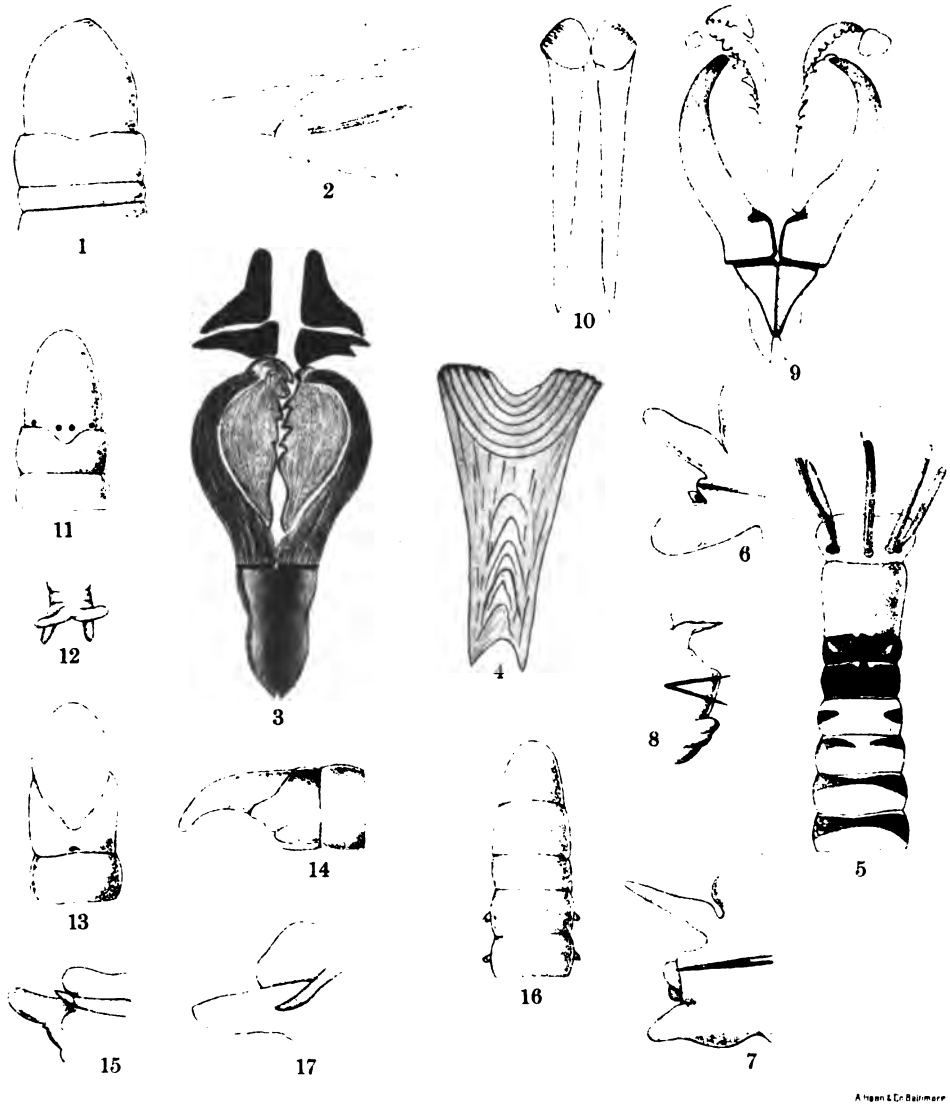
FIGURES 8 to 12, *Marphysa simplex* Treadwell. Fig. 8, anterior end × 7. Fig. 9, tenth parapodium × 23. Fig. 10, forty-fifth parapodium × 23. Fig. 11, posterior parapodium × 23. Fig. 12, maxilla × 23.

FIGURE 1, *Marphysa californica* Moore, anterior end × 7.5.

FIGURES 2 to 6, *Paramarphysa teres*, Treadwell. Fig. 2, anterior end × 15. Fig. 3, thirteenth parapodium × 185. Fig. 4, posterior parapodium × 185. Fig. 5, maxilla × 45. Fig. 6, mandible × 45.

FIGURES 7 to 13, *Lysidice fusca* Treadwell. Fig. 7, anterior end × 13. Fig. 8, pygidium × 13. Fig. 9, first parapodium × 48. Fig. 10, tenth parapodium × 48. Fig. 11, posterior parapodium × 48. Fig. 12, maxilla × 41. Fig. 13, mandible × 20.

FIGURES 14 to 17, *Lysidice parva* Treadwell. Fig. 14, anterior end × 23. Fig. 15, parapodium × 100. Fig. 16, maxilla × 68. Fig. 17, mandible × 41.



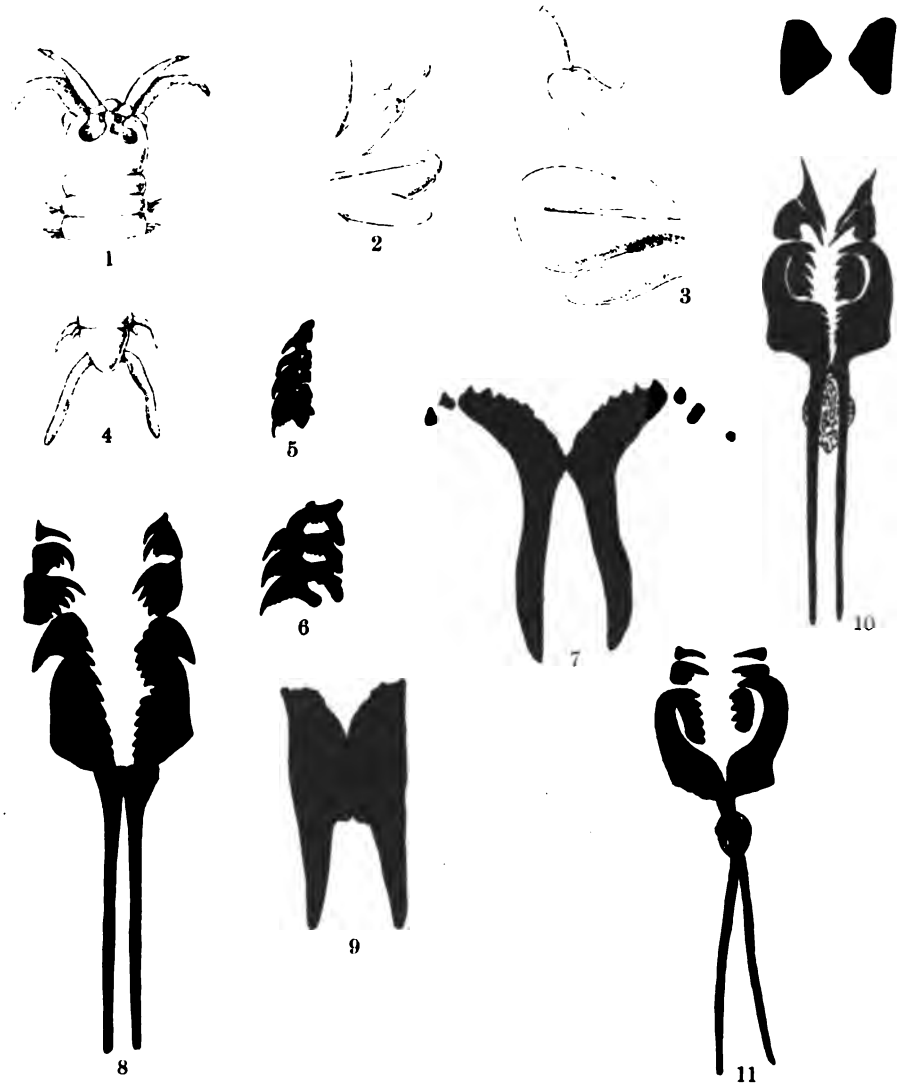
FIGURES 1 to 4. *Lumbrinereis japonica* v. Marenzeller. Fig. 1, anterior end × 10. Fig. 2, ninety-eighth parapodium × 28. Fig. 3, maxilla × 23. Fig. 4, mandible × 35.

FIGURES 5 to 10, *Nicidion fusca-fasciata* Treadwell. Fig. 5, anterior end × 10. Fig. 6, first parapodium × 62. Fig. 7, tenth parapodium × 48. Fig. 8, posterior parapodium × 48 Fig. 9, maxilla × 48. Fig. 10, mandible × 48.

FIGURES 11 and 12, *Arabella dubia* Treadwell. Fig. 11, anterior end × 20. Fig. 12, pygidium × 23.

FIGURES 13 to 15, *Drilonereis lumbricus* Treadwell. Fig. 13, dorsal view of anterior end × 10. Fig. 14, lateral view of anterior end × 10. Fig. 15, parapodium × 22.5.

FIGURES 16 and 17, *Drilonereis paucidentata* Treadwell. Fig. 16, anterior end × 20.5. Fig. 17, parapodium × 220.



FIGURES 1 to 7, *Dorvillea australiensis* McIntosh. Fig. 1, anterior end × 6. Fig. 2, first parapodium × 41. Fig. 3, tenth parapodium × 41. Fig. 4, pygidium × 20. Fig. 5, anterior plates of the maxillary series × 41. Fig. 6, median plates of the maxillary series × 41. Fig. 7, mandible × 41.

FIGURES 8 and 9, *Arabella dubia* Treadwell. Fig. 8, maxilla × 68. Fig. 9, mandible × 68.

FIGURE 10, maxilla of *Drilonereis lumbricus* Treadwell × 20.

FIGURE 11, maxilla of *Drilonereis paucidentata*, Treadwell × 55.

IX.

POLYCHÆTOUS ANNELIDS COLLECTED AT FRIDAY HARBOR, STATE OF WASHINGTON, IN FEBRUARY AND MARCH 1920.

By A. L. TREADWELL,

Professor of Zoölogy in Vassar College.

Thirty-seven figures.

POLYCHAETOUS ANNELIDS COLLECTED AT FRIDAY HARBOR, STATE OF WASHINGTON, IN FEBRUARY AND MARCH 1920.

By A. L. Treadwell.

The following is a partial report of the results of an investigation on the Pacific annelids, conducted during the season of 1920 under the auspices of the Department of Marine Biology of the Carnegie Institution of Washington, Dr. A. G. Mayor, Director. It comprises descriptions of certain new species of polychætes collected by the writer in the vicinity of Friday Harbor, State of Washington, in February and early March 1920, with notes on some previously described. Grateful acknowledgment is made to Professor T. C. Frye, Director of the Puget Sound Biological Station, who put the resources of his laboratory at my disposal.

Family SYLLIDÆ.

Autolytus varius Treadwell.

Autolytus varius Treadwell. 1914, New Syllidæ from San Francisco Bay, collected by the U. S. S. *Albatross*. Univ. of Calif. Pub. in Zoology, vol. 13, No. 9, page 237, figs. 4 to 7.

The original description was taken from a single preserved specimen. The first ones obtained in 1920 were collected by Mr. J. Little in the herring trap near the shipyard at Friday Harbor and were swimming at the surface. Later, others were found in the same locality. The anterior end (fig. 1) agreed in structure with the original description, except that the tentacular cirri are more nearly equal to the antennæ in size than was there stated. The palps are very small, are directed ventrally, and are not visible from the dorsal surface. They are fused for more than half their length, the free portion being in the form of a blunt cone. The smaller eyes (black) are shown as lying directly over the (stippled) larger ones. The first five somites are not very sharply marked off from one another, but two sets of longitudinal lines extend along the dorsal surfaces of somites 1 to 4. The inner ones mark off median areas which are successively wider from before backward. Lateral to each is a fainter line running parallel to it. These areas are very clearly outlined, but not much elevated above the general surface. The natatory setæ are excessively delicate and are blunt-ended, though the end may turn slightly so as to be seen in profile, and then look as if sharp-pointed. Behind the brood pouch are 60 or more somites gradually narrowing toward the pygidium and with successively smaller cirri. There are two anal cirri larger than the dorsal cirri immediately in front of them. The animals vary greatly in size, for while most were 30 mm. long, one of only 10 mm. was carrying a brood pouch with young.

In the living animals are two color phases: (1) Light green body-color with a white brood-sac containing eggs in cleavage stages. The coloration is most intense through the median body-region, and is there most marked as a dark-green line crossing each somite toward its posterior end, continued on to the posterior face of the parapodium to the point of attachment of the dorsal cirrus and covering the basal joint of the cirrus. The distal part of the cirrus is white. (2) The color varies through shades of reddish brown, the brood-sac being bright salmon. In these the brood-sacs contained larvæ. This color difference is quite independent of the color of the larvæ them-

selves, but may perhaps be influenced by their state of development. I was, however, unable to discover any constant relation between depth of coloration and degree of development of the larvæ.

The oldest larvæ I found were 0.75 mm. long and had two setigerous somites (fig. 2). The anterior margin of the head is rounded and has two pairs of sharp spines, one ventral to the other. There are two pairs of eyes, the ventral ones being represented in the figure by stippling, as showing through the tissues of the head. There are two bands of cilia around the head, and behind these a tuft of cilia on either side. It is possible that here, also, is a continuous band, but I was unable to determine whether this is the case. Two setigerous somites follow these, with very minute setæ apparently like the compound ones previously described. A band of cilia surrounds the body near the posterior end.

Family PHYLLODOCIDÆ.

Eteone maculata, new species.

A single specimen of over 300 somites, the posterior end regenerating. The total length was 75 mm., width of prostomium 0.5 mm., greatest body-width including the parapodia 3 mm. The prostomium (fig. 3) is rather broadly rounded at its anterior margin, with the lateral margins sloping slightly outward posteriorly, the diameter at the posterior margin being thus about one-third greater than at the anterior. In the dorsal median line of the posterior margin is a blunt, backwardly directed lobe. There are 4 small triangular tentacles.

Dorsally the first somite is longer on either margin than in the mid-line. It bears on either side 2 conical, rather thick, cirri of which the ventral ones are the larger. The second somite is about two-thirds as long as the first, its parapodia being placed more ventrally than is the case in succeeding somites. The flattened dorsal cirri characteristic of this family are very small on somite 2 and gradually increase backward, reaching their full size on about somite 10. Throughout they are rather thick, but never very large or prominent.

In alcohol the general body-color is yellow, with the cirri, especially posteriorly, a distinct golden color. Beginning with somite 4, each somite except 9 bears on its dorsal surface a prominent spot or spots. If there is but one it usually lies in the median line; if two, they tend to lie one on either side, just dorsal to the parapodium. If three, one may lie in the median line and one over each parapodium. It seems probable that these are highly variable in distribution, but material is lacking for the determination of this point. Similar spots, though much smaller and more variable in their distribution, occur on the ventral surface. No eyes are visible on the preserved material.

The first parapodium (fig. 4) has the characteristic form, but the parts are all very small (cf. fig. 4 with 5). There is a rounded setal lobe and a ventral cirrus situated postero-ventrally to the setal portion and united to it for almost its entire length. The twentieth parapodium (fig. 5) has an entire anterior and a bifid posterior lip to the setal lobe. As before, the ventral cirrus is largely fused with the setal portion, while the large dorsal cirrus is more nearly free.

The setæ are all compound and similar, with long basal joints (fig. 6). The terminal joint varies somewhat in width, but in other respects those of a bundle are all alike. Each is flattened, tapers to an acute point, and may be more or less bent.

Collected at Friday Harbor. Type in the American Museum of Natural History.

Eteone tuberculata, new species.

The type specimen is 106 mm. long, with a width of 1 mm. at the posterior margin of the prostomium. The width of body, including parapodia, is 4 mm.

The prostomium (fig. 7) has a rounded anterior margin between the bases of the tentacles, but the lateral areas, where the tentacles are attached, are straight and

parallel to one another. Behind the bases of the tentacles each lateral margin slopes gently outward, so that the posterior margin of the prostomium is about equal to its antero-posterior diameter. The posterior dorsal surface has a distinct tubercle situated in a rather deep backward indentation of the anterior margin of the peristomium. This tubercle may possibly be regarded as homologous to the third tentacle found in the genus *Eulalia*, but in character of the setæ this specimen differs widely from the latter genus. The tentacles are short-lanceolate and equal in size.

On its anterior margin the peristomium is wider than the prostomium and widens still more posteriorly, so that its posterior margin is about twice as wide as the prostomium. The anterior margin is incurved, forming a bay in which the tubercle on the prostomium lies, and the 4 equal-sized tentacular cirri are on the lateral surfaces. Ventral to these the peristomium is noticeably wider than it is on the dorsal surface. The second somite is about half as long as the first, and succeeding somites increase in width up to about the ninth. The mouth is bounded dorsally by the prostomium, laterally and ventrally by the first somite. The dorsally directed anus has a rounded lip and there is one pair of short and rather stout anal cirri.

The first parapodium is on somite 2 and has rounded postsetal and presetal lobes and a well-developed ventral cirrus (fig. 8), the dorsal cirrus being absent. There is a single acicula, and a row of compound setæ with rather short terminal joints. In later parapodia the dorsal cirrus appears as a rather thick but not very large lobe. It is small on somite 2 but increases in size farther back. A well-developed parapodium is shown in figure 9. The presetal lobe is notched, while the postsetal is rounded. In preserved material all of the dorsal cirri are deep brown in color, being especially in the smaller specimens much darker than the general body-color. There is a sub and a supra tuft of cilia, the former (fig. 10) with a slender basal portion enlarged and toothed at the end. The terminal joint is flat, and at the base is as broad as the apex of the basal portion, but it rapidly narrows to an acute apex with a row of minute denticulations along the concave margin. The supra-acicular bundle is composed of similar setæ, but the terminal joint is longer and more slender.

Collected at Friday Harbor. Type in the American Museum of Natural History.

Family LEODICIDÆ.

Lumbrinereis zonata Johnson.

Lumbriconereis zonata Johnson, 1901. The Polychæta of the Puget Sound Region. Proc. Boston Soc. Nat. Hist. 29; pp. 408 to 409, pl. 9, figs. 93 to 100.

This was the commonest annelid in the Friday Harbor collections. Measurements of living annelids, especially members of this genus where there is very great power of contractility, are of little value, but I found that preserved specimens vary in length from 100 to 300 mm. with a prostomial width of not more than 1.5 mm. and a body-width of 2 mm. The general body-color in life is dark brown with a marked iridescence, and it can be distinguished from the only other species of this genus that I collected in this locality by the fact that in the other (*L. cervicalis*, see below) there is a noticeable brown nuchal band, easily seen with the naked eye, and the body is a lighter brown. Under the hand lens (in *L. zonata*) a transverse band of brownish-gray dots may be seen running across the middle of each somite, and these may be the foundation of the dark transverse bands which appear in preserved material and were the reason for Johnson's specific name. This transverse dark band, appearing only in preserved material, occurs after preservation in a number of Lumbrinereids, so that its value as a specific character is small. The prostomium is not quite as acutely pointed anteriorly as in Johnson's figures and the anterior peristomial line is straight rather than concave. The following additions are made to Johnson's description.

The mandibles (fig. 12) are transparent, except where marked along their cutting edges with dark pigment. This is darkest at the outer angles and diminishes in

amount toward the middle line. The halves are united for almost their entire length. In the maxilla (fig. 11) the carriers are rounded basally but narrowed at about their middle. The forceps are rather slender and only faintly curved. The right proximal plate has 5 teeth, the left 4, the second pair each has 2, the third pair each has 1. All parts of the maxilla are jet-black and there are collections of black pigment in the chitin outside of the plates which are not shown in the figure. There are two pairs of anal cirri (fig. 13) approximately equal in size, the dorsal a little closer together than the ventral.

Lumbrinereis cervicalis, new species.

Individuals of this species are rather small as compared with others of this genus, the average size being 80 mm. in length and 1 mm. prostomial width. They are easily recognized in life by a noticeable dark-brown band crossing the dorsal surface of the first two somites (fig. 14) and by the yellowish body-color. Visible under a lens are minute brownish lines running longitudinally along the dorsal surface of the prostomium. These are variable in size and color.

The prostomium in living animals is rounded and usually a little broader than long, though in preserved material the postero-anterior diameter may be the longer. The first two somites (fig. 14) show dorsally the pigment band, which does not extend on to the ventral surface (fig. 15). Throughout most of the body is a prominent brown spot just ventral to the parapodium in each somite, and other pigment spots are scattered irregularly over the dorsal surface. There are 4 equal-sized, short anal cirri.

The parapodium has the form characterisitc of this species (fig. 16 is drawn from the tenth), and there are no noticeable differences in form, except that the posterior ones are more slender. In the anterior parapodia are both simple and compound setæ. The dorsalmost are simple, each long, curved, and fine-pointed, with a wing along its convex margin (fig. 17). Toward the ventral surface are others of similar form, but shorter and less noticeably curved. The compound setæ (fig. 18) lie in the middle of the tuft. The terminal joint has a number of minute teeth at the apex, which is covered with a hood. A continuation of this hood extends for a short distance down the basal portion, but at the joint between the basal and apical portions is a slight constriction, as if the hood were divided into two parts. Behind about the fortieth parapodium both these forms of setæ disappear and their place is taken by a second form of simple seta resembling the compound ones of anterior somites if the two parts of these had fused (fig. 19). The stalk is long and the apex has a number of minute teeth, covered by a hood which extends for a short distance down the shaft.

The maxilla is small and is dark brown in color (fig. 20). The carriers are sharp-pointed posteriorly and roughly triangular in form, with a notch in each on the outer face near the anterior end. The forceps are slender and gently curved. The right proximal plate has 5, the left 4 teeth, the second pair has 4 each, and the terminal pair 2. There is more or less pigment in the chitin bordering these plates which is not shown in the figure. The mandible (fig. 21) is uncolored, except for dark pigment patches on the outer anterior margins.

Collected first at Boat Bay and later in Newhall's lagoon at Friday Harbor. It occurs also in limited numbers in other localities in this vicinity.

The type is in the American Museum of Natural History.

Onuphis stigmatis, new species.

Collected in considerable numbers in False Bay, Friday Harbor, in sand exposed at low tide. One specimen was in a tube of sand grains, but most seemed to be lying loose. This was unexpected and it may be that I overlooked the other tubes, though a special effort was made to find them. The single complete specimen of the animal collected at this time was 80 mm. long, with a prostomial width of about 1.5 mm.

In the living animal the basal joints of the tentacles show a very little pigmentation, but the remainder of the tentacles, the palps, and the nuchal cirri are colorless. A

broad band of dark-brown pigment extends across the peristomium and is continued anteriorly into a patch of the same color on either side (fig. 22). It is stated by some writers that the nuchal cirri in *Onuphis* are carried on the peristomium. This I am convinced is a mistake and I regard the apparent first somite as a fusion of somites 1 and 2. The apparently second somite is thus really somite 3. A very faint pigment line crosses the posterior fourth of this somite, while behind this two bands occur in each somite—one at the parapodial level and the other near the constriction between the somites, the latter being the smaller. This continues to about somite 20 and from here posteriorly the pigment gradually becomes less distinct, the patch near the intersegmental constriction disappears, while remnants of the other persist as patches lying along the sides of the somites. They eventually disappear at about the region of the thirtieth somite. In the living animal the red dorsal blood-vessel and the bright-red gills are noticeable features in the coloration. While these latter colors are lost in the preserved material, the course of the dorsal blood-vessel is marked by a row of spots due to coagulated blood. The pigmentation of the anterior region is retained, but the posterior end of the body is colorless in the preserved material.

There are two pairs of anal cirri (fig. 23); one pair (the dorsalmost), very long and slender, the others very short.

The prostomium (fig. 22) is rounded on its anterior margin with the frontal ten-tentacles rather widely separated, the latter elliptical in outline with a narrowed base. The cirrophores of the tentacles have not more than 3 basal rings, not very sharply marked off, and a terminal portion longer than the basal. These cirrophores extend nearly to the apices of the frontal tentacles. The outer paired tentacles have terminal portions about twice as long as the cirrophores, the other tentacles with the terminal portions as much as six times the length of the cirrophores. The terminal portions are slender, rounded at the apex, the unpaired a very little shorter than the inner paired. A very small and inconspicuous eye lies on either side postero-laterally from the base of the inner paired tentacle. The mouth is at the bottom of a broad pit, which is bounded dorsally by the two very prominent rounded palps, and ventrally by a 2-lobed prolongation of the first somite. In form and size these lobes are very similar to the palps, but unlike them, are not fused in the midline.

The nuchal cirri arise on the anterior border of the (morphologically) second somite. They are conical in form and extend to as far as the terminal third of the cirrophores of the inner paired tentacles. Dorsally somites 1 and 2 are considerably shorter than the prostomium and are together about one-third as long as somite 3. Somite 3 is continued laterally into the first parapodium, of which only the dorsal cirrus is shown in the figure. This parapodium extends to a short distance in front of the anterior margin of somites 1 and 2. The parapodium of somite 4 also shows a forward extension, but this is not so apparent in later somites. Anteriorly the dorsal surface of the body is rounded and the parapodia have in consequence a ventral shifting, but behind somite 12 this rounding disappears and the parapodia assume a lateral position, while at the same time the dorsal median line shows a shallow groove.

There is a large, dorsally directed anal opening. A ventral view of the pygidium (fig. 23) shows the anal cirri, but the preservation was too poor to make it possible to draw the terminal somites and their relation to the pygidium.

The first parapodium (fig. 24) has a very long cirrus-like postsetal lobe, with rounded presetal lobe. In the specimen figured the dorsal cirrus was bifid at the end, a quite exceptional condition, the usual cirrus being rounded at the apex, with a swollen base, and only a little longer than the postsetal lobe. The ventral cirrus is large, lanceolate, arising from a constricted base. There are 2 not very large aciculæ, which taper slightly toward the apex until they reach the surface, when they suddenly narrow into very acute tips. A small tuft of needle aciculæ extends into the base of the dorsal cirrus. There is a tuft of 5 or 6 very long "semi-compound" setæ.

The tenth parapodium (fig. 25) shows the ventral cirrus changed to the form of a vertically arranged, rather prominent pad, the postsetal lobe and the dorsal cirrus

retaining essentially their earlier character. A number of aciculæ (4 in the one drawn) occupy the center of the setal lobe. One of these was drawn out into a slender, curved, acutely pointed tip, and it is probable that the others had originally this structure, which had been broken off. There is a tuft of needle setæ in the dorsal cirrus.

The setæ form a dense tuft of four kinds: dorsalmost is a small tuft of very slender pectinate; next to these simple ones, long and very sharp-pointed, with the terminal portion very much flattened and provided with lateral wings; ventral to these, some of quite similar form, but with the terminal part broader and shorter than in the dorsalmost ones. Under high power they show a finely pilose character, as if fine hairs were thickly distributed over the terminal region. At the ventral end of the series is a bundle of compound setæ.

The thirty-fifth parapodium (fig. 26) has a conical setal portion with a rounded lobe on its anterior face. Dorsally it carries a gill which is larger than the dorsal cirrus and extends to beyond the dorsal midline. Long needle aciculæ extend into the dorsal cirrus. The aciculæ are of two kinds: (1) slender forms with the free end terminating in a very sharp point (fig. 27); (2) a much heavier form with apical and subapical teeth narrowing into a neck just proximal to the subapical tooth and then broadening into the shaft (fig. 28). Only one of each is drawn in figure 26, but there were two of one and four of 2 in the actual specimen. In place, the larger one looked as if hooded, but this was evidently due to the fact that it lay in a slight depression, so that it was partly covered by a transparent fold of the outer skin of the body.

The semicompound setæ (fig. 29) at first appear compound, but closer examination shows that what looks like a terminal joint is really not completely separated from the basal. There is a large terminal tooth and there are two unequal subterminal ones, with a hood covering them all, the apex of this hood thickened. The simple setæ (fig. 30) enlarge rapidly toward the apex and then narrow to an acute point. The compound setæ (fig. 31) are slender, with a smooth, pointed terminal joint without teeth or hood. The pectinate setæ (fig. 32) have long shafts with about 12 very slender teeth.

The gills begin on about the twentieth somite, the most anterior ones smaller than those farther back. There is never more than one branch (fig. 26). In the single entire specimen the last gill was on the twenty-fifth somite in front of the pygidium.

The jaw apparatus is extremely soft and delicate and difficult to remove without injury. In the one figured the halves of the maxillæ had fallen apart and the unpaired plate had turned over (fig. 33). Normally the inner margins of the carriers are in contact. Except for the dark pigmented patches indicated in the figure and the tips of the teeth, all parts are thin and transparent. The carriers are triangular in form, the forceps rather heavy and not much curved. Each proximal paired plate has 6 teeth, the distal paired has 10 on the right and 8 on the left. The unpaired has 7 well-developed teeth and 1 very small one. The mandible (fig. 34) has pointed lateral wings and faintly marked concentric lines on the beveled portion. Near the middle line each has a prominent dark band running lengthwise.

Type in the American Museum of Natural History.

Family SPIONIDÆ.

Polydora californica Treadwell.

Polydora californica Treadwell, 1914, Polychætous Annelids of the Pacific Coast in the Collections of the Zoological Museum of the University of California. Univ. of Calif. Pub. in Zoology, vol. 13, p. 203, pl. 12, figs. 23 to 29.

This species was abundant in Newhall's lagoon at Friday Harbor and was collected at False Bay. To the original description may now be added that of the pygidium, which was absent from the specimens from California. This has the form of a broad, very shallow funnel (fig. 35).

Family CIRRATULIDÆ.

Cirratulus robustus Johnson.

Cirratulus robustus Johnson, 1901, Polychæta of the Puget Sound Region, Proc. Boston Soc. Nat. History, 29, p. 423, pl. 14, figs. 149, 150.
Cirratulus cingulatus Johnson, loc. cit., p. 422, pl. 14, figs. 145 to 148.

Living specimens are usually dark olive-green in color, but in some cases they may be almost black. The region in front of the tentacles is yellowish brown in most cases, but one specimen was nearly colorless. On the tentacles are bright scarlet spots looking like the eyes of a sabellid, arranged in an irregular row. The prostomium (fig. 36) has on either side a row of dark eye-like spots. The first somite has a curved anterior margin following the outline of the corresponding margin of the prostomium. Laterally and ventrally this somite is shorter than on the dorsal surface. A prolongation of the second somite extends dorsally into the first. Later somites are much shorter than either of these.

A comparison of Johnson's descriptions of his two species shows that in the general form of the body, the distribution of the cirri, the form of the setæ, the general form of the head region, and the arrangement of the eye-spots the two are alike, the only differences being that in *C. cingulatus* the somites are ringed and the large cirri are on somite 8, while in *robustus* the somites are smooth and the large cirri are on somite 4. In this genus the first three somites are long and there is a tendency toward surface wrinkling. It seems to me that the difference Johnson described in tentacle position was an error, due to mistaking surface wrinkles for somite boundaries, and I have therefore combined the two species.

Collected at Turn Island and Minnesota Reef near Friday Harbor.

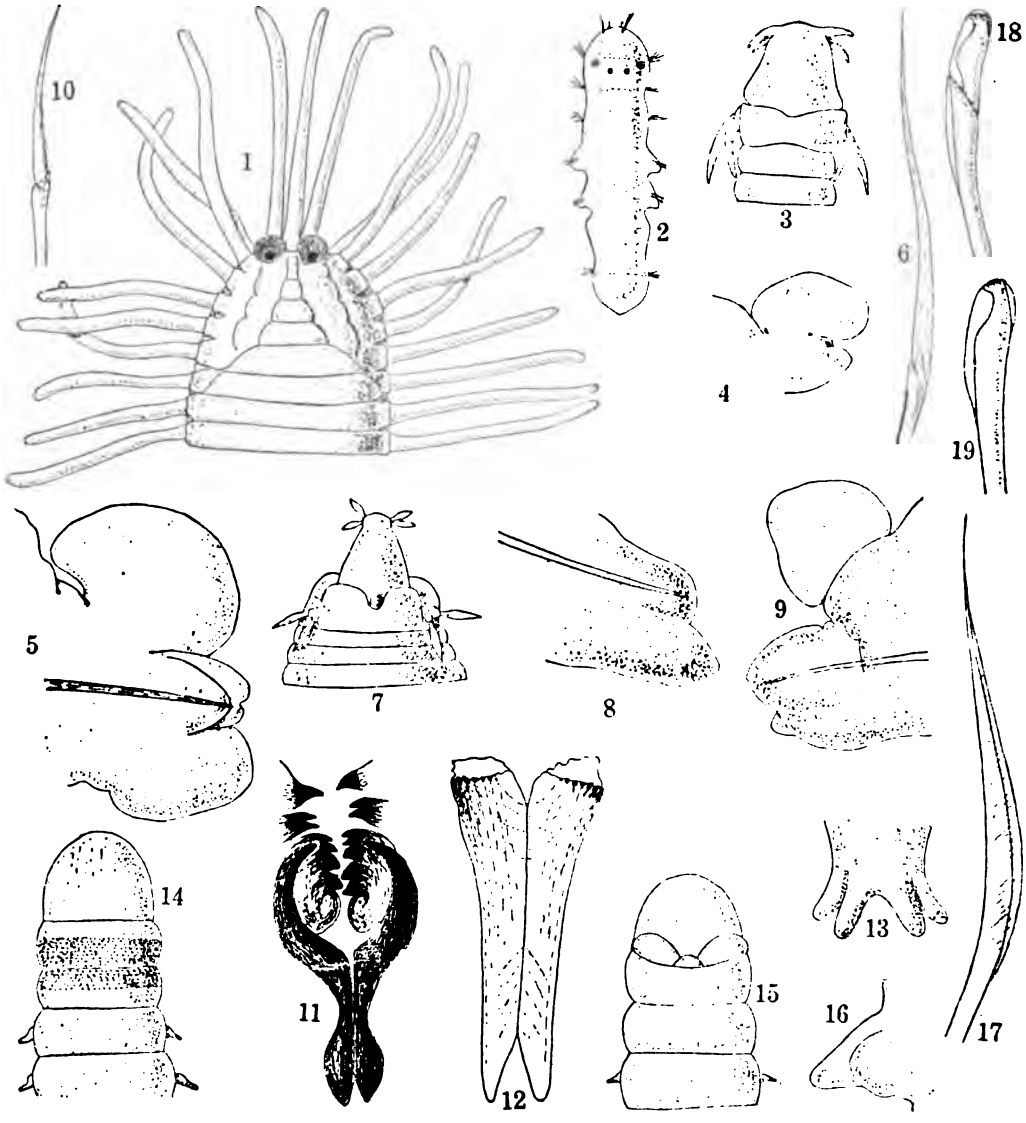
Family OPHELIIDÆ.

Ammotrypane brevis Moore.

Ammotrypane brevis Moore, 1906. Proc. Acad. Nat. Sci. Phil. 58, p. 354, with 1 figure.

Specimens of this genus collected at Friday Harbor, while one-third longer than the single specimen from Alaska on which Moore founded this species, agree with his description in every detail except two. The first is that the prostomium is not as definitely dorso-ventrally flattened as in Moore's description, a difference which might be due to the preservation, and the second is the structure of the pygidium. Moore notes: "If perfect, as it appears to be, the pygidium presents striking characters. The large, median spoon-shaped lobe of *A. aulogaster* is absent and represented only by a minute slender process. The lateral lobes are much larger, obliquely truncated above, and slightly indented at the end." In the Friday Harbor specimens the pygidium has a short hood, overhanging dorsally the anal opening, and continuing so far toward the ventral surface that the ventral margins are almost in contact. The margin of this lobe is drawn out into cirrus-like processes. In all of the three individuals at my disposal the ventralmost of the processes are thick, elongate-elliptical in outline with constricted bases (fig. 37). Dorsal to these the margin of the hood bears a series of slender processes. In the three specimens there were, respectively, 4, 5, and 7 of these processes, varying in size, but always slender. A single slender cirrus arises from the ventral mid-line of the body, and may extend beyond the other processes as in the one figured, though in another it was shorter. In the third specimen it had evidently been lost.

Collected at Friday Harbor.



FIGURES 1 TO 19.

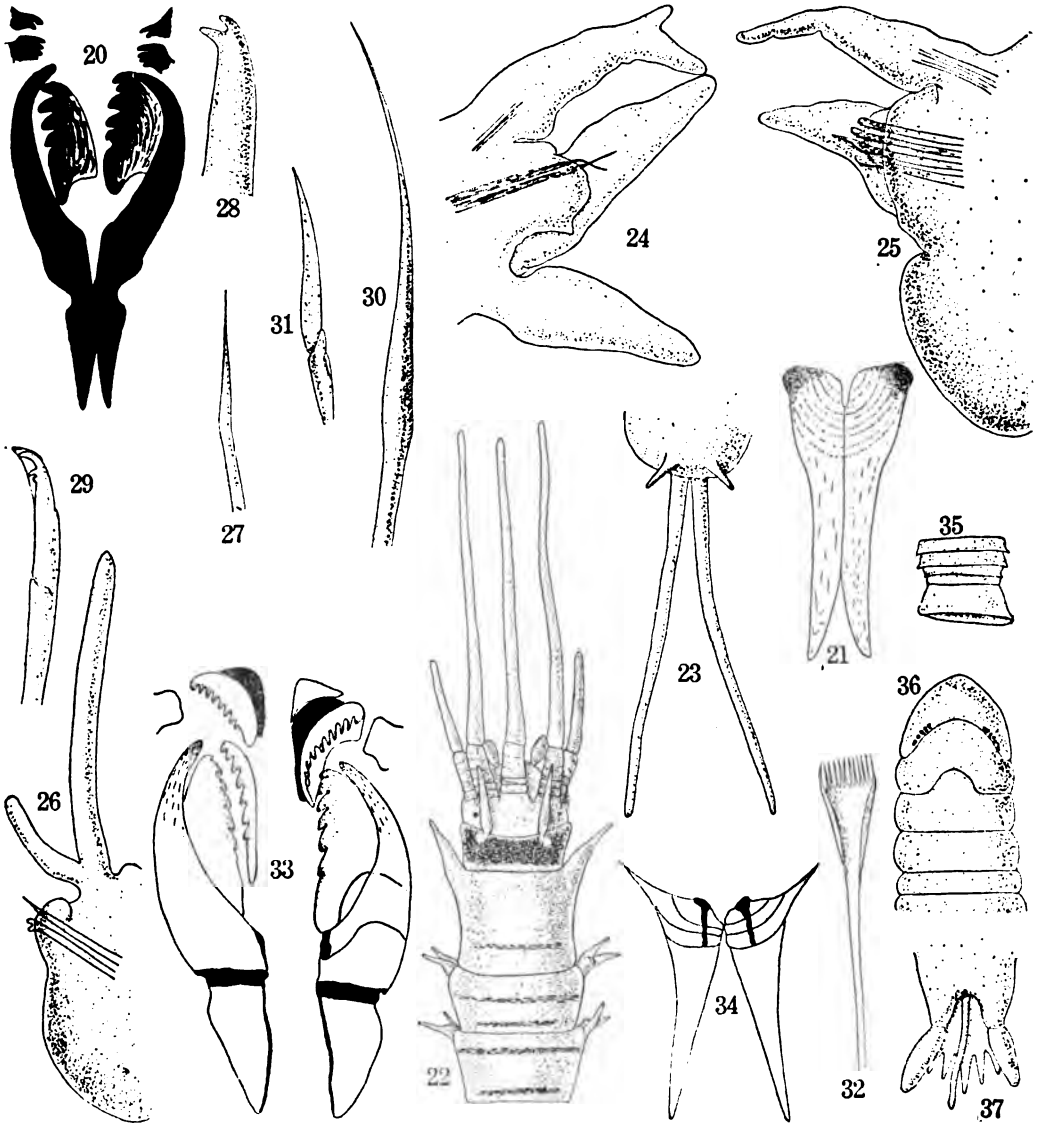
1 and 2. *Autolytus varius* Treadwell. Fig. 1, anterior end, × 10; fig. 2, larva, × 52.

3 to 6. *Eteone maculata* new species. Fig. 3, anterior end, × 15; fig. 4, first parapodium, × 68; fig. 5, twentieth parapodium, × 45; fig. 6, seta, × 240.

7 to 10. *Eteone tuberculata* new species. Fig. 7, anterior end, × 10; fig. 8, first parapodium, × 68; fig. 9, later parapodium, × 68; fig. 10, compound seta, × 250.

11 to 13. *Lumbrinereis sonata* Johnson. Fig. 11, maxilla, × 41; fig. 12, mandible, × 41; fig. 13, anal cirri, × 18.

14 to 19. *Lumbrinereis cervicalis* new species. Fig. 14, anterior dorsal view, × 10; fig. 15, anterior ventral view, × 10; fig. 16, first parapodium, × 47; fig. 17, simple seta, × 220; fig. 18, anterior compound seta, × 280; fig. 19, posterior simple seta, × 280.



FIGURES 20 TO 37.

20 and 21. *Lumbrinereis cervicalis* new species (continued). Fig. 20, maxilla, × 28; fig. 21, mandible, × 28.

22 to 34. *Onuphis stigmatis* new species. Fig. 22, anterior dorsal view, × 15; fig. 23, posterior ventral view, × 15; fig. 24, first parapodium, × 68; fig. 25, tenth parapodium, × 68; fig. 26, parapodium from middle of body, × 45; fig. 27, acicula, × 250; fig. 28, acicula, × 250; fig. 29, semi-compound seta, × 250; fig. 30, seta from tenth parapodium, × 250; fig. 31, compound seta from tenth parapodium, × 250; fig. 32, pectinate seta, × 500; fig. 33, maxilla, × 45; fig. 34, mandible, × 45.

35. *Polydora californica* Treadwell. Pygidium, × 13.

36. *Cirratulus robustus* Johnson. Anterior dorsal view, × 10.

37. *Ammotrypane brevis* Moore. Pygidium, × 20.

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